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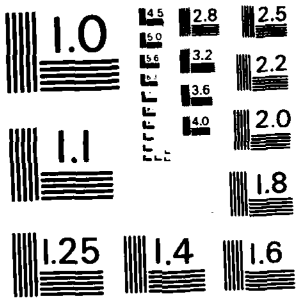

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RSRE MEMORANDUM No. 3525

ROYAL SIGNALS & RADAR ESTABLISHMENT

AN INVESTIGATION INTO THE EFFECT OF SIDELOBE CANCELLATION UPON THE GENERAL SIDELOBE LEVEL

Authors: J E Summers and
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PROCUREMENT EXECUTIVE,
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ROYAL SIGNALS AND RADAR ESTABLISHMENT

Memorandum 3525

Title: AN INVESTIGATION INTO THE EFFECT OF SIDELOBE CANCELLATION UPON THE GENERAL SIDELOBE LEVEL

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SUMMARY

The effect of implementing sidelobe cancellation (SLC) upon the overall aerial pattern sidelobe level has been investigated theoretically and experimentally. In general, cancellation results in a significant raising of the overall sidelobe level and careful selection of the auxiliary aerial pattern is required to minimise this effect.

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RSRE MEMORANDUM 3525

AN INVESTIGATION INTO THE EFFECT OF SIDELOBE CANCELLATION UPON THE GENERAL SIDELOBE LEVEL

J E Summers and N P Wright

LIST OF CONTENTS

1 INTRODUCTION

Sidelobe cancellation (SLC) is a technique employed to reduce the effects of interference entering a radar or communications system via the aerial sidelobes[1]. As its name suggests, the technique involves cancelling the sidelobe through which the unwanted signal is being received. In order to achieve cancellation of a specific sidelobe of an aerial it is necessary to add an antiphase signal of equal level to that received by the sidelobe in question. This cancels the particular sidelobe of concern, but what effect does the addition of this signal have upon the remainder of the aerial pattern and the associated radar or communications system?

This memorandum reports upon a preliminary investigation conducted into this question from both a theoretical and a practical approach.

2 SIDELOBE CANCELLATION SYSTEM

The basic sidelobe cancellation system is illustrated in Fig. 1. Essentially an auxiliary aerial is employed to obtain a sample of the unwanted signal which is entering the main aerial via a sidelobe; this signal from the auxiliary aerial is then adjusted in phase and amplitude, such that an equal but antiphase signal is added via a coupler to cancel the unwanted signal in the main channel.

In practice the cancellation is made adaptive by the use of components such as vector modulators to provide the correct amplitude and phase of the auxiliary signal, and correlators to provide the feedback for adaptation. The only requirement on the auxiliary channel is that it can provide a sufficiently high level of the unwanted signal to cancel that in the main channel. Ideally this requirement is achieved by having the auxiliary aerial gain sufficiently high so that it exceeds the main aerial sidelobe gain plus losses in the coupling process. If necessary the auxiliary channel signal may be boosted by amplification, but this has the penalties of an increase in the receiver noise figure and a deterioration in the path match between the main and auxiliary channels. The latter aspect would limit the bandwidth of the cancellation.

If more than one sidelobe is required to be cancelled, then additional loops, ie auxiliary aerial plus vector modulator, etc, must be added. There must be at least as many loops as there are interference sources (sidelobes) to be cancelled, preferably more as the adaptation time with an equal number may be slow[2].

3 SIDELOBE CHARACTERISTICS

It is instructive to review the characteristics of aerial sidelobes. The salient characteristics for this study are their amplitude and phase.

The maximum power level likely to be encountered is -13 dB relative to the main beam, this being the first sidelobe of a uniformly illuminated aperture. The minimum level is likely to be around -50 dB, or -60 dB at lowest. In general the sidelobe level will fall off with angle off main beam, until a plateau is reached. This plateau represents a practical lower limit of sidelobe performance set by effects such as mechanical tolerances and constructional imperfections, edge diffraction, scattering and blockage. The lobes adjacent to the main beam are referred to as the close-in sidelobes, whilst the plateau is referred to as the far sidelobe level.

Let us now consider the phase variations. The standard method of aerial pattern calculation essentially involves dividing the aerial aperture into a number of elementary areas and performing a vector summation of the contributions from all these elemental areas in the far field. Mathematically this corresponds to a Fourier transform of the aperture distribution. For the normal constant phase aperture distribution this yields a lobing pattern, in which the sidelobe phase is either 0° or 180° with adjacent sidelobes being in antiphase. However this method of calculation is only strictly valid for the main beam and first few sidelobes, since in practice there are other effects or contributions that must be taken into account. Some of these effects are: direct feed contribution, diffraction at the edge of the aperture, and scattering eg from supports or radome. Such sidelobes, formed by the addition of several contributions, would not be expected to possess such a regular phase relationship as 0° or 180°, or

indeed a smooth amplitude structure; rather their phase will be somewhat arbitrary. Supporting evidence for this hypothesis may be found by observing the practical sidelobe structure, which does not bear much relationship to the smooth-lobed, monotonically decaying form given by the standard Fourier transform (of the "assumed" smooth aperture distribution, rather than a practical one perturbed by the aforementioned effects) approach alone.

In summary, the sidelobes will be of a power level of -13 to -60 dB relative to the main beam. The first few sidelobes will generally be alternately of phase 0^o and 180^o whereas those further out will not be so constrained and may have any phase angle.

4 THEORETICAL ESTIMATES

Some theoretical estimate of the change in main aerial sidelobe level due to the cancellation process may be obtained using array theory and simple vector addition considerations.

4.1 ARRAY THEORY

The main and auxiliary aerials form a two-element array and if the amplitude variations of the individual normalised aerial patterns are $A_M(\theta)$ and $A_A(\theta)$ respectively, where θ is the angle off boresight, then the array pattern $A(\theta)$ is given by

$$A(\theta) = A_M(\theta) + a\, A_A(\theta) \qquad (1)$$

where a is the level of the auxiliary aerial pattern relative to that of the main aerial. In general, a will be complex ie

$$a = a_o \exp j\, \phi \qquad (2)$$

where a_o is the relative amplitude and ϕ the relative phase.

In order to proceed to obtain some numerical values it is convenient to employ simple representative analytic functions for the main and auxiliary aerial patterns. Accordingly we shall assume that the auxiliary aerial pattern is the ideal, usually postulated one ie omnidirectional with

$$A_A(\theta) = 1 \qquad (3)$$

and employ the analytic functions for uniform and cosine-tapered aperture distributions for the main aerial pattern, on the basis that these cover the extreme cases of high and low sidelobe aerials. The relevant functions are

$$\frac{\sin(\pi\psi)}{\pi\psi} \qquad \text{Uniform Illumination} \qquad (4)$$

and

$$\frac{\pi}{4} \cdot \left\{\frac{\sin(\psi+\pi/2)}{\psi+\pi/2} + \frac{\sin(\psi-\pi/2)}{\psi-\pi/2}\right\} \qquad \text{Cosine Taper} \qquad (5)$$

where $\psi = \frac{D}{\lambda}\sin\theta$, D being the aperture dimension.

In practice these functions, derived by aperture distribution transformation only accurately predict the close-in sidelobes, those at wider angles being determined by edge diffraction and scattering etc as discussed in section 3. However these functions are quite suitable for the task in hand. Note that the phase of alternate sidelobes is o and π. First sidelobes are -13 and -23 dB for the uniform and cosine distributions respectively and the corresponding far sidelobes considered in this exercise were -40 and -60 dB respectively.

Array patterns were generated for auxiliary aerial levels corresponding to the full range of sidelobe levels. A 3^o aerial beamwidth, typical of many radar systems, was selected and hence D/λ was set at 17 for the uniform and 23 for the cosine distribution. Computations were truncated beyond -60 dB, values below this being set at -60 dB for plotting purposes.

Considering first the uniform distribution representing a poor radar aerial sidelobe performance, Figs. 2 to 4 represent the addition of auxiliary pattern levels of -17.6, -25.7 and -32.2 dB to cancel the 2nd, 6th and 13th sidelobes respectively. Fig. 5 is a summary of the resultant peak sidelobe envelopes.

Cancellation of the close-in high level sidelobe region requires the addition of an auxiliary signal of the same magnitude as this region ie one considerably greater than the level of the sidelobes further out (larger angles off boresight), to which it is also added in the cancellation process. As a result the sidelobe level at wider angles than the cancelled lobe is dominated by the auxiliary aerial contribution to the array pattern. This is clearly seen in Fig. 2 where cancellation of the second sidelobe (-17.6 dB) has raised the far out sidelobe level from -33 dB to -17 dB. Sidelobes adjacent to that cancelled have also been raised, but to a lesser extent eg first sidelobe increased by 4 dB. The main beam has even been affected, specifically reduced by 1.2 dB. Cancellation of an intermediate level sidelobe (6th sidelobe at -25.7 dB) has a similar but less dramatic effect as shown by Fig. 3, whilst cancellation of a far sidelobe (13th at -32.2 dB) has minimal effect on the close-in region and causes the far out sidelobe region to be raised by $\sim$ 6 dB as shown in Fig. 4. It is interesting to note that the effect of this lower level addition is analogous to the contribution associated with aperture blockage resulting in alternate sidelobes being raised and lowered.

A similar pattern is exhibited for the case of the low sidelobe aerial as illustrated by Figs. 6 to 9. However the effect on the far sidelobe region of cancelling close-in sidelobes is more dramatic on account of the much lower far sidelobe level.

These array pattern calculations show that in the process of cancelling a particular sidelobe which is receiving interference, there is a general raising of the aerial sidelobe level. The most acute situation is when cancelling a close-in or high level sidelobe, in which case the far sidelobe level is considerably raised as a result of being dominated by the auxiliary, rather than the main aerial contribution.

The effect on the far sidelobes is somewhat reduced if the auxiliary aerial is not the ideal of an omnidirectional aerial usually suggested for cancellation systems, but one whose pattern falls off with angle, but is above that of the main aerial sidelobes.

4.2 VECTOR ADDITION CONSIDERATIONS

If at some pattern angle we represent the main aerial amplitude by a unit vector and that of the auxiliary by a vector of amplitude a and phase ϕ then the resultant combined power (r^2) will be given by

$$r^2 = 1 + a^2 + 2a \cos\phi \tag{6}$$

and may range from constructive ($\phi = 0$) to destructive interference ($\phi = 180^o$).

Consider first the case of $a = 1$ and the resultant as a function of phase angle ϕ as illustrated in Fig.10. This situation represents the level of sidelobes originally at the same level as that to be cancelled. The curve is only plotted from 0^o to 180^o since it reflects about 180^o. The boundary between constructive and destructive interference (0 dB) may be obtained from equation (6) by putting $r^2 = 1$, whence

$$\phi = \cos^{-1} -\tfrac{1}{2} = 120^o \tag{7}$$

the main points shown by Fig. 10 are that for random phase; combination with sidelobes other than that to be specifically cancelled is more likely to be constructive and that nulls are far more sensitive to phasing than peaks. Out of 360^o of phase, 240^o (67%) is associated with constructive and 120^o (33%) with destructive interference. Although an undesirable characteristic from a sidelobe aspect, it is a useful one from a main signal aspect.

Nulls are very sensitive to phase as indicated by Table 1 computed on the assumption of correct auxiliary aerial amplitude contribution ($a = 1$). Note for example that only 10% of the possible phase angles will yield a cancellation of 10 dB. It is thus unlikely that sidelobes other than that intentionally cancelled will be nulled.

TABLE 1 - PHASE ACCURACY FOR GIVEN NULL DEPTH

NULL DEPTH (dB)	ANGULAR ACCURACY (DEGREES ± FROM 180°)
0	60
10	18.2
20	5.7
30	1.8
40	0.6

The sensitivity of the null depth or cancellation to amplitude balance assuming perfect antiphasing ($\phi = 180^o$) is shown in Table 2 below. Although amplitude and phase are not directly comparable, it appears that amplitude balance is less important than phase balance in cancellation.

TABLE 2 - AMPLITUDE ACCURACY FOR GIVEN NULL DEPTH

NULL DEPTH (dB)	AMPLITUDE ACCURACY (dB)
0	$-\infty$ to +6
10	-3.3 to +2.4
20	-0.9 to +0.8
30	± 0.3
40	± 0.09

As discussed in section 3, with the exception of the first few sidelobes, we may regard the sidelobe phase as random and hence we require to estimate the mean value of equation (6) with phase. Performing the necessary integration we find that

$$r^2 = 1 + a^2 \tag{8}$$

ie incoherent or signal power addition.

Sidelobe levels will be in the range -20 to -50 dB and Table 3 illustrates the effect on these sidelobe levels of auxiliary aerial contributions added to cancel such sidelobes. Extremes (constructive and destructive interference) and mean (incoherent addition) levels are displayed.

The dominant feature of Table 3 is that addition of high levels of auxiliary signal to cancel the higher aerial sidelobes has a dominant and drastic effect on the low level sidelobes. Also cancellation of a far out sidelobe will on average raise the far out sidelobe plateau by about 3 dB.

5 INFLUENCE OF THE AUXILIARY AERIAL PATTERN SHAPE

The main requirement upon the auxiliary aerial pattern is that its gain must exceed that of the main aerial sidelobes it is to cancel. Lack of actual auxiliary aerial gain, or more precisely, auxiliary channel gain, may be made up for by additional amplification in the auxiliary channel, but this will increase the overall receiver noise figure and may degrade the channel path matching and hence the bandwidth of the cancellation.

However, we need to consider the influence of the shape of the auxiliary pattern upon the effectiveness of the cancellation system, in order to establish if enough attention is paid in practice to this aspect of the design. We now proceed to examine the influence of the shape by discussing some specific examples.

TABLE 3 - RESULTANT SIDELOBE LEVELS $\left(\frac{\text{MEAN}}{\text{EXTREAM RANGE}}\right)$

MAIN AERIAL SIDELOBE (-dB) \ AUXILIARY AERIAL LEVEL (-dB)	20	30	40	50
20	17 (MEAN) $-\infty \rightarrow 14$ (RANGE)	19.6 $23.3 \rightarrow 17.6$	20 $20.9 \rightarrow 19.2$	20 $20.3 \rightarrow 19.7$
30	19.6 $23.3 \rightarrow 17.6$	27 $-\infty \rightarrow 24$	29.6 $33.3 \rightarrow 27.6$	30 $30.9 \rightarrow 29.2$
40	20 $20.9 \rightarrow 19.2$	29.6 $33.3 \rightarrow 27.6$	37 $-\infty \rightarrow 34$	39.6 $43.3 \rightarrow 37.6$
50	20 $20.3 \rightarrow 19.7$	30 $30.9 \rightarrow 29.2$	39.6 $43.3 \rightarrow 37.6$	47 $-\infty \rightarrow 44$

First consider the "standard" omnidirectional aerial, this is shown superimposed on the main aerial pattern in Fig. 11. Clearly an omnidirectional aerial may have insufficient gain for cancellation of the first few sidelobes without resorting to additional amplification on the auxiliary channel at the expense of the receiver noise figure. Furthermore it is apparent that sidelobes of similar level to that cancelled will be raised on average by 3 dB, sidelobes much higher than that cancelled will be minimally raised, but those lower than that cancelled will be raised towards that of the cancelled lobe ie the far sidelobe level is drastically degraded.

Secondly consider an auxiliary aerial whose shape follows that of the main aerial sidelobes as illustrated in Fig. 12. It is apparent that cancellation of any sidelobe will raise the overall sidelobe envelope on average by 3 dB all over the pattern (incoherent addition).

Finally, consider an auxiliary aerial whose shape is narrower than that of the main aerial sidelobes as illustrated in Fig. 13A, and consider say cancellation of the third sidelobe for which the relative auxiliary and main aerial levels are illustrated in Fig. 13B. The cancellation process will drastically raise the close-in sidelobe level and have no significant effect on those far out.

It is clear that careful choice of auxiliary aerial pattern shape is highly desirable, the ideal probably being one whose shape follows the main aerial sidelobe template leading to an overall sidelobe degradation of some 3 dB, rather than a drastic raising of the close-in sidelobes for a "narrow" auxiliary pattern or far out sidelobes for a "broad" eg omni-auxiliary aerial pattern. With non-matched shapes, one could elect not to cancel some regions of the sidelobes and thereby avoid the excessive pattern degradation eg only cancel close-in lobes with a narrow auxiliary pattern and vice-versa.

6 PRACTICAL MEASUREMENTS

Cancellation experiments were carried out at S and X band using the experimental configuration shown in Fig. 1. Cancellation was achieved by manual adjustment of the phase shifter and attenuator ie a non-adaptive system. In addition, phase measurements were performed at X-band to examine the hypothesis expounded in section 3 of an arbitrary phase structure existing over most of the sidelobe region as opposed to the idealised values of o and π.

6.1 AERIAL AND EXPERIMENTAL DETAILS

S-band experiments were conducted at a frequency of 3.2 GHz and in the H-plane only, employing a large Cassegrain aerial of elliptic cross-section (2.3 m x 1.8 m) having a gain of approximately 35 dB. The auxiliary aerial selected was a waveguide horn of aperture dimensions 6.7 cm x 5.9 cm (H-plane by E-plane). Main and auxiliary aerial patterns are shown in Fig. 14 and the sidelobes selected for cancellation are numbered. The comparatively slow fall off of the close-in lobes is a result of the shaped sub-reflector (Williams[3,4]) to give a more uniform ie high gain aperture illumination. Aerial pattern measurements were made on an outdoor range.

X-band experiments were conducted at a frequency of 9.4 GHz in both planes using a front fed parabolic aerial of some 46 cm diameter with a gain of approximately 30 dB. The auxiliary aerial selected was open ended waveguide. Main and auxiliary patterns are shown in Figs. 15 and 16 and again the sidelobes selected for cancellation are numbered. The increased sidelobe levels (wings) at around $\pm 90^{\circ}$ in the main aerial pattern are associated with direct feed radiation, and the lack of symmetry in the E-plane auxiliary pattern is due to the proximity of the main aerial ie the installation effects. Aerial pattern measurements were conducted in the RSRE Anechoic chamber. Phase measurements were undertaken using a network analyser.

6.2 RESULTS

The results of the S and X band cancellation experiments plus the phase measurements will now be presented separately.

6.2.1 Phase Measurements

For experimental convenience (short indoor range) these were only undertaken at X-band. It was considered unnecessary to repeat the measurements at S-band, since a similar result was anticipated and the objective of the phase measurements was just to confirm that the aerial sidelobe phases were sufficiently irregular to warrant the use of incoherent, rather than coherent addition of main and auxiliary

aerial patterns in assessment work. Care was taken to locate and rotate the aerial "about" its phase centre, since at X-band, small offsets eg one inch off the phase centre will considerably affect the results.

Auxiliary aerial phase plots are shown in Figs. 17 and 18. The general feature is a relatively constant phase over the centre of the main beam, followed by a gradual fall off with angle.

Main aerial phase plots are shown in Figs. 19 and 20. The dominant feature of these plots is that there is no regular structure. The lack of a regular amplitude structure, even in the close-in sidelobes, is indicative of an irregular phase structure. The relatively constant phase regions around $\pm 90^{\circ}$ are associated with the direct feed radiation (spillover) which dominates this region of the pattern (see Figs. 15 and 16).

These phase measurements show that for assessment purpo , incoherent (power) addition may be employed, indeed vector a tion based on assumed theoretical phase values of o and π would b ther erroneous.

6.2.2 S-Band Cancellation Measurements

Samples of the results displaying the effect of implementing sidelobe cancellation upon the normal aerial pattern are shown in Figs. 21 to 25. Also shown for reference is the auxiliary aerial pattern superimposed at the appropriate level for cancellation. The non-linearity of the power scale is due to non-linearity in the logarithmic amplifier used in the experiment, which also makes it difficult to superimpose precisely the auxiliary and main aerial patterns.

In general, the effect of cancelling a particular sidelobe is to raise the overall sidelobe level. Sidelobes much greater than the auxiliary aerial level are little affected, unless fortuitiously they were in co- or anti-phase with the auxiliary aerial pattern. An example of this latter point is the close-in sidelobes of Fig. 23. Sidelobes of a similar level to that of the auxiliary aerial pattern are raised approximately 3 dB as one would expect, whilst the regions of the aerial pattern at a much lower level than that of the auxiliary pattern tend to rise to around the level of the auxiliary pattern.

Deep cancellation of sidelobes other than that deliberately selected for cancellation is in general unlikely, since the phase and amplitude requirements would not be satisfied. However cancellation of a few other sidelobes has occurred as illustrated by Fig. 24 (3 others) and Fig. 25 (4 others), the null depths being 10 to 20 dB. Note in these instances the close match ie amplitude balance of the auxiliary pattern to the main aerial sidelobes.

6.2.3 X-Band Cancellation Measurements

Samples of the H-plane cancellation results are shown in Figs. 26 to 28. With reference to the discussion on auxiliary pattern shapes (section 5), the auxiliary pattern is really too narrow for cancelling wide angle sidelobes since it results in a catastrophic raising of the close-in sidelobes as illustrated by Fig. 28. The effect of cancelling close-in sidelobes such as 1 and 2 for which the auxiliary pattern is a better match, has a less dramatic effect on the close-in sidelobe region as illustrated by Fig. 27. The effect of applying cancellation however is to raise the general sidelobe level in those regions where the auxiliary aerial level is comparable or much greater than the main aerial sidelobe level.

Samples of the E-plane cancellation results are shown in Figs. 29 to 31. The auxiliary pattern is broad, tending to the omnidirectional category. It may be seen from Figs. 29 and 30 that cancellation of a high level sidelobe has dramatically raised the far out sidelobe level, it has even altered the main beam level. For the latter effect to occur the main and auxiliary aerials phases must have been similar in this region.

Finally Fig. 32 illustrates the validity of assuming power ie incoherent addition of the main and auxiliary patterns to yield the resultant for assessment purposes. This is seen to be a suitable working approximation.

7 MULTILOOP CONSIDERATIONS

If more than one sidelobe is to be cancelled ie the system is to cope with more than one source of interference, then additional loops ie auxiliary aerial, vector modulator, correlator etc must be added to the cancellation system. Thus instead of the resultant pattern being main aerial pattern + auxiliary aerial pattern contribution as given by equation (1), we now have the resultant aerial pattern as:

main aerial pattern + auxiliary aerial 1 contribution +
auxiliary aerial 2 contribution + auxiliary aerial 3 contribution, etc

with the result that the overall sidelobe degradation will in general increase with the number of loops. However the rate of increase of degradation is unlikely to increase linearly with the number of loops, and one would expect some saturation effect, probably occurring for a small number of loops, caused by the fact that the auxiliary aerial patterns now control the sidelobe level.

8 SYSTEM IMPLICATIONS

It is apparent that implementation of sidelobe cancellation, whilst cancelling some specific sidelobes and hence reducing the interference received, will result in an overall increase in the aerial sidelobe level. The system degradation associated with a general rise in sidelobe level will depend upon the particular system and the environment into which it is deployed. A major consideration would be whether the improvement obtained by cancelling the interference would be negated by effects associated with the general increase of sidelobe level. An associated consideration would be how close the original sidelobe level was to the minimum acceptable for the system.

An important point to note is that sidelobe cancellation is usually only applied on reception and hence the increase in sidelobe level associated with the implementation of SLC does not apply to the transmitter's aerial pattern, only to the receiver's, ie a one and not a two-way effect.

Sidelobe considerations for a communications system are:

- ECCM ie susceptibility to jamming/interference
- Susceptibility to multipath ie signal corruption
- Susceptibility to intercept and direction finding (DF)
- EMC

The first two items are associated with the receive path only, the third with the transmit path only whilst EMC applies to both the transmit path (illuminating other systems) and the receive path (receiving unwanted transmissions from other systems).

If sufficient loops were available to cancel the jammers or sources of interference, then there would almost certainly be a net benefit from implementing SLC, for unless there was a severe multipath problem, communication would have been restored by cancellation of the jamming.

For ground-based radars, the sidelobe considerations are:

- ECCM
- Reduction of short-range ground clutter
- Reporting of targets at false azimuths
- EMC

Again if there were sufficient loops available to cancel all the jammers, then the radar would continue to operate, albeit with reduced performance. The short-range ground clutter may have been increased and hence targets close to the original threshold would now be lost.

Similar considerations apply to shipborne radars, except that multipath off the sea may be a more severe problem especially when tracking sea-skimming missiles.

The airborne pulse-doppler radar situation is probably the most serious as clutter is generally extensive in both range and velocity. A raising of the sidelobe level will result in an increase in clutter, and the detection range is reduced in regions of range velocity space where detection was clutter rather than noise limited, and also in those regions where detection was previously noise limited, but as a result of an increase in sidelobe level are now clutter limited. An an example, a 3 dB increase in sidelobe level is associated with a 3 dB increase in clutter power (only receive path sidelobes degraded by SLC) corresponding to a 16% reduction in detection range in the range-velocity cells associated with this increase in clutter.

9 CONCLUSIONS

The effect of implementing sidelobe cancellation is in general to cause a significant raising of the overall aerial sidelobe level.

When sidelobe cancellation is implemented, the resultant aerial pattern is the vector summation of the main aerial pattern and the auxiliary aerial pattern, the latter being added at the appropriate level to cancel the sidelobe in question.

Sidelobes much greater than the auxiliary pattern will in general be minimally affected, those of a similar level raised by approximately 3 dB, whilst those much less than the auxiliary aerial pattern will be raised to around its level. It is this last case that causes the serious sidelobe degradation and results in a significant raising of the far sidelobe level.

Sidelobe degradation may be minimised, but not eliminated, by careful selection of the auxiliary pattern shape.

As the phase structure tends to be random after the first few sidelobes, then power wise ie incoherent addition of main and auxiliary aerial patterns may be employed for assessment purposes.

In general, sidelobe degradation will result in system performance degradation, the extent of which will depend upon the system and the environment in which it is deployed.

Since it is apparent that the use of SLC can cause significant performance degradation under some circumstances, it is clearly far better to design an aerial to have low sidelobes, rather than employ one of poor performance with cancellation.

10. ACKNOWLEDGEMENT

The authors wish to acknowledge the contribution of C Golightly to the S-band measurement programme and thank J Clarke for his criticism of the manuscript.

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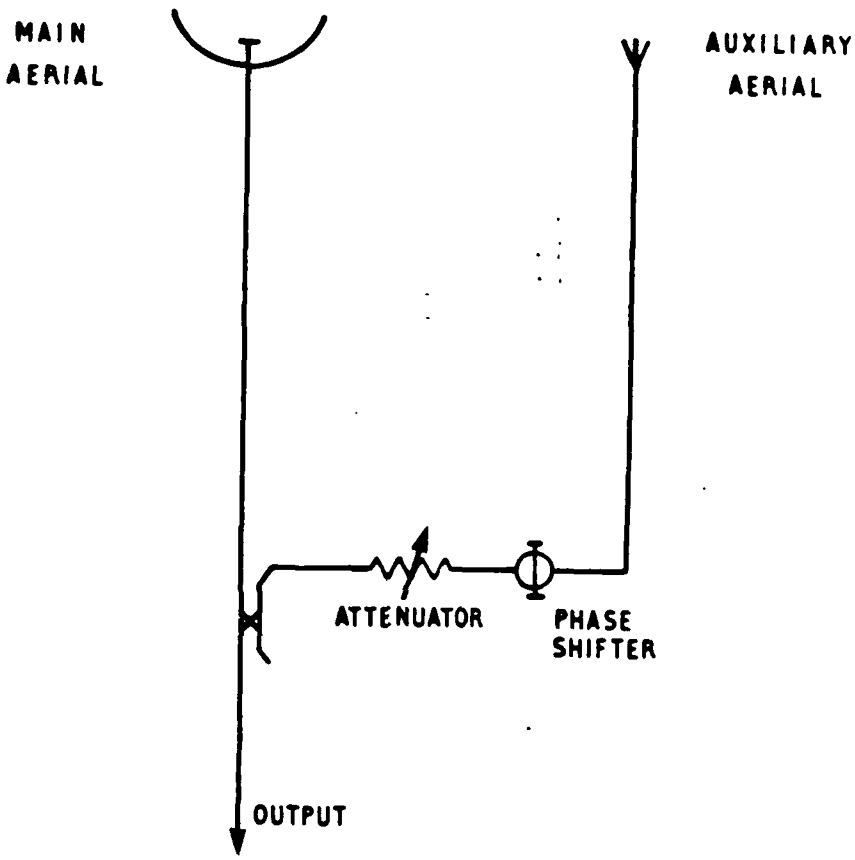

FIG. I. BASIC SIDELOBE CANCELLATION SYSTEM

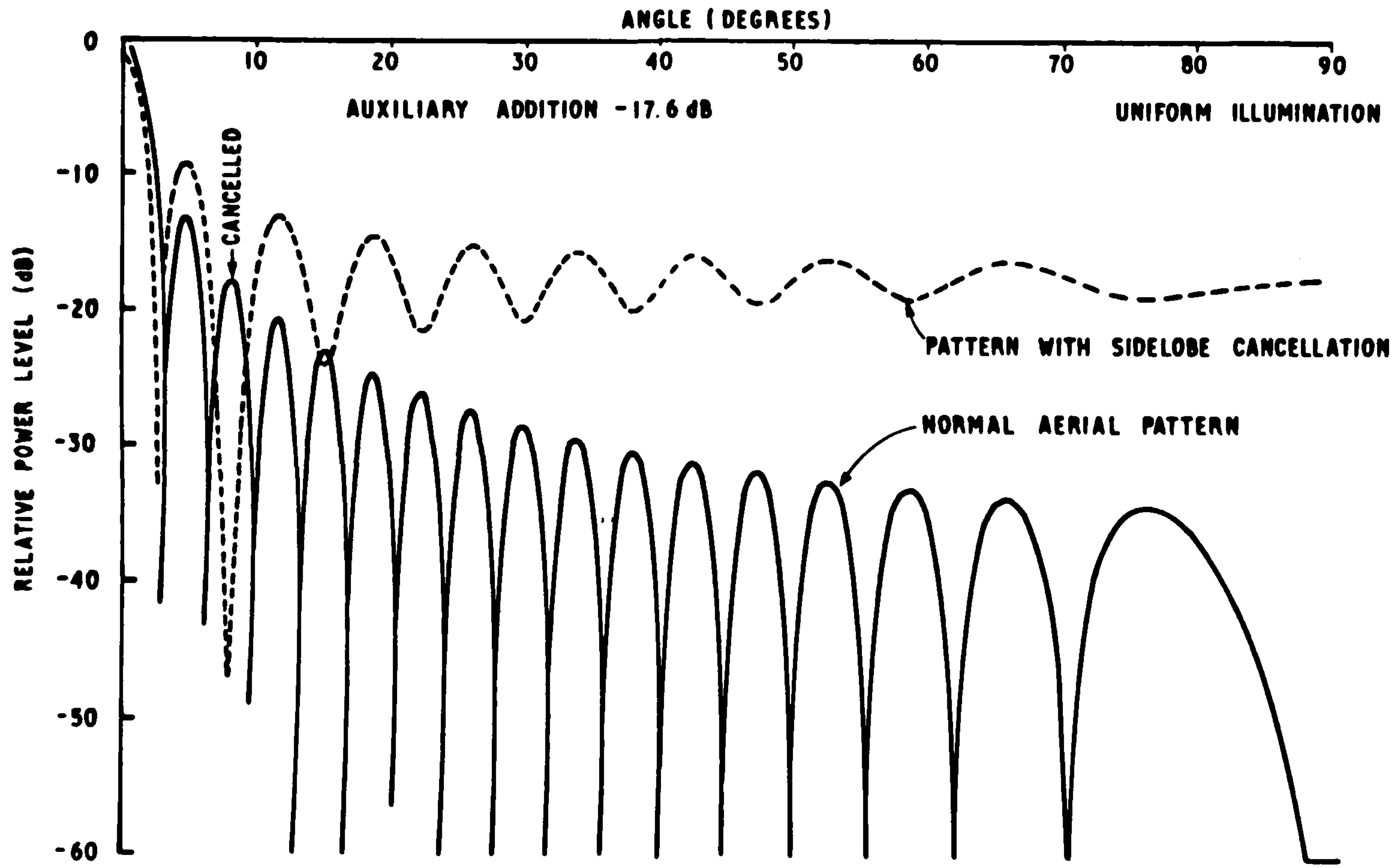

FIG. 2. EFFECT ON THE RADIATION PATTERN OF CANCELLING THE SECOND SIDELOBE

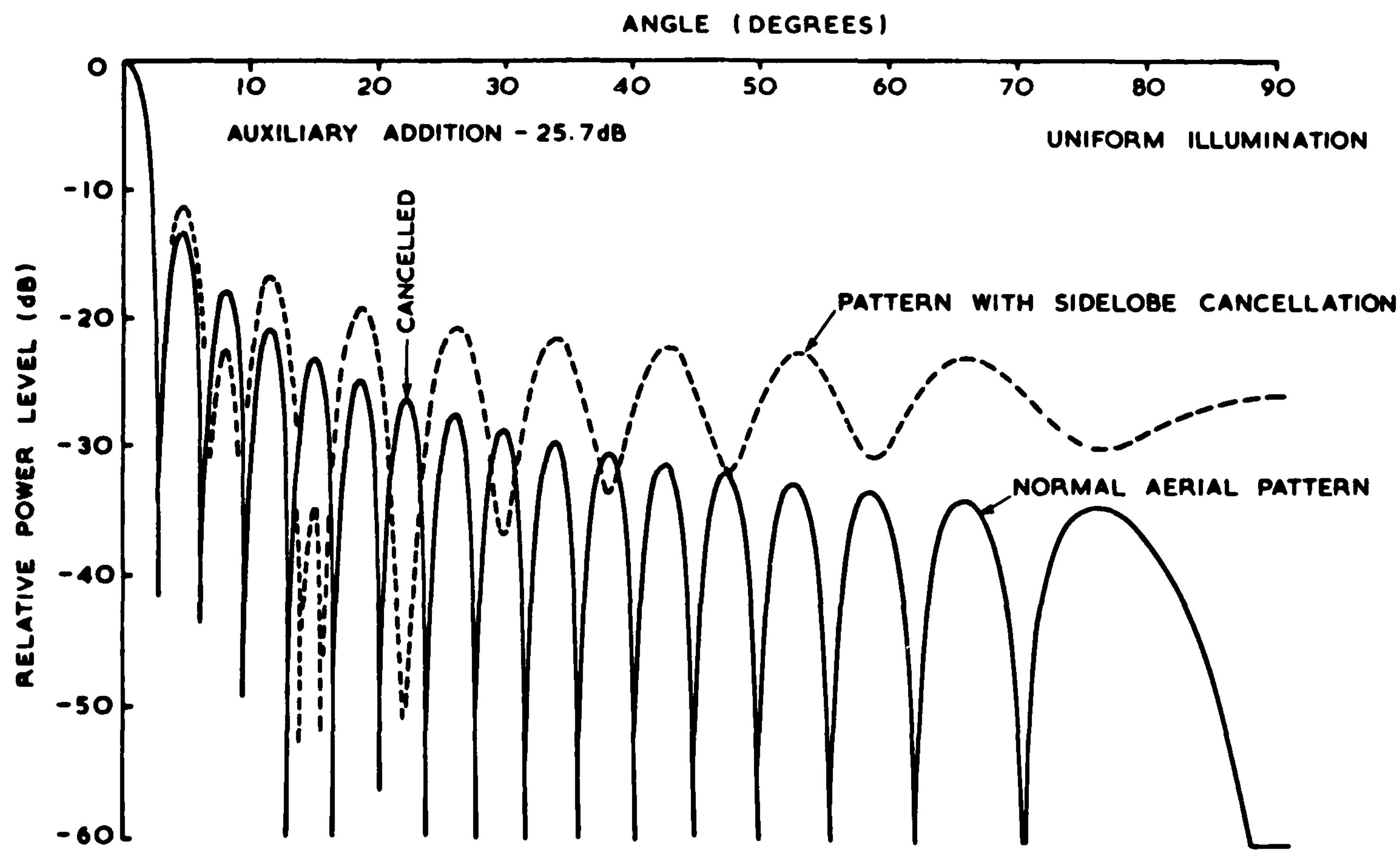

FIG. 3. EFFECT ON THE RADIATION PATTERN OF CANCELLING THE SIXTH SIDELOBE

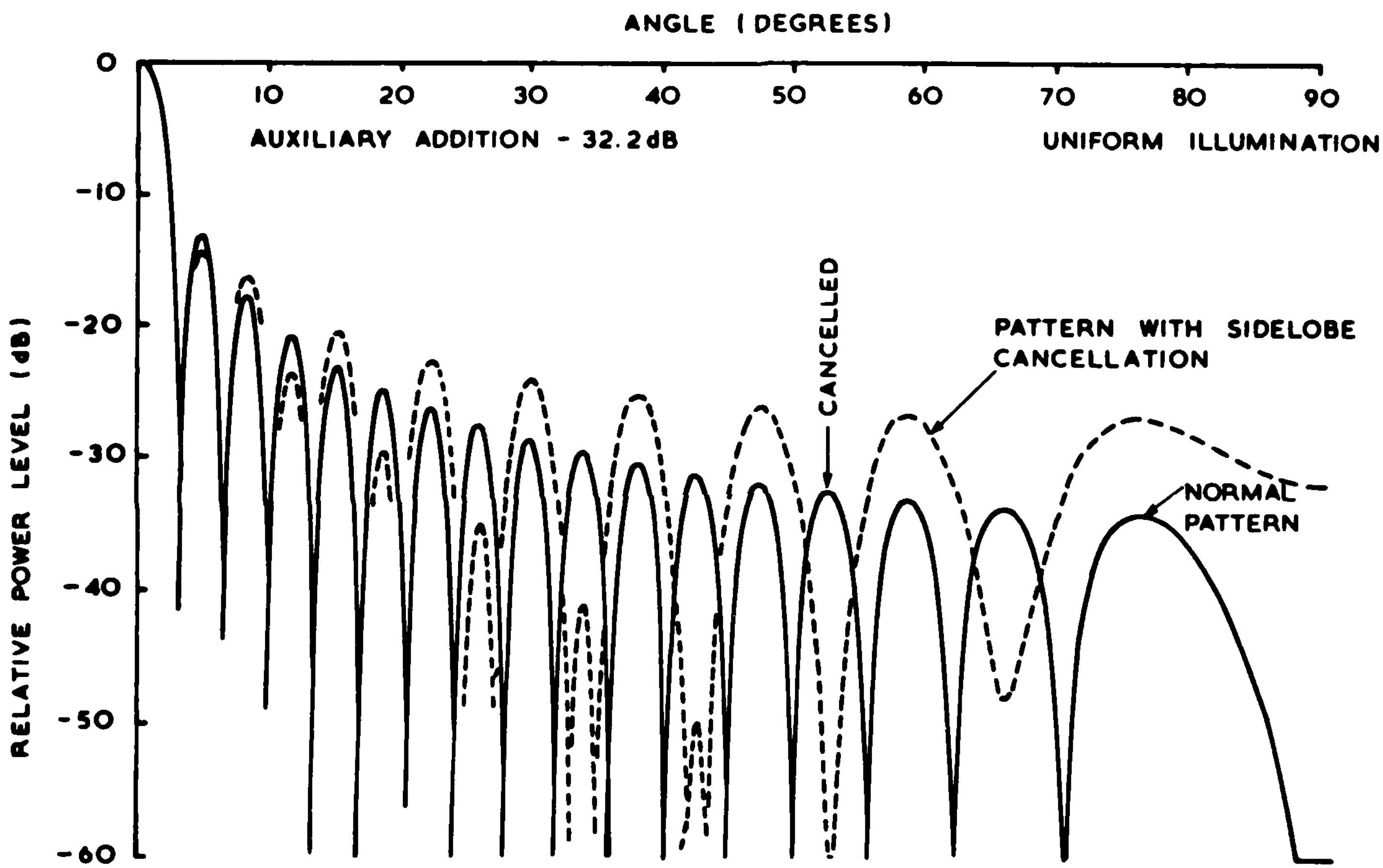

FIG. 4. EFFECT ON THE RADIATION PATTERN OF CANCELLING THE THIRTEENTH SIDELOBE

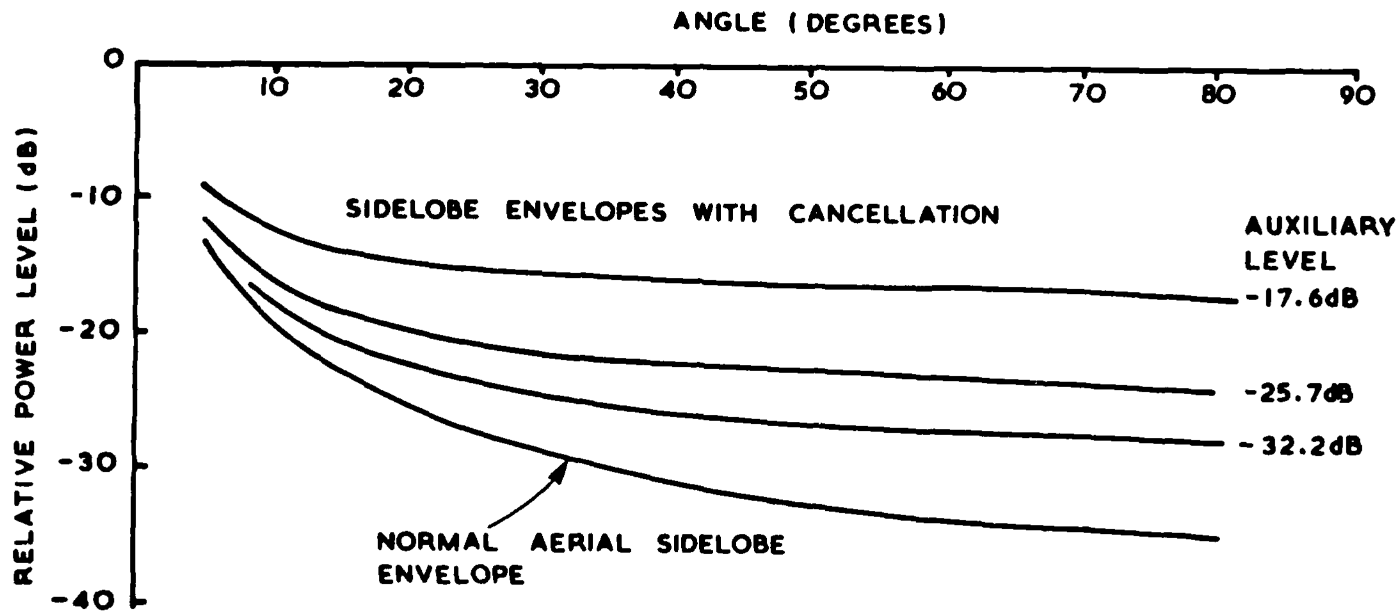

FIG. 5. PEAK SIDELOBE ENVELOPE RESULTING FROM IMPLEMENTING SIDELOBE CANCELLATION - UNIFORMLY ILLUMINATED APERTURE

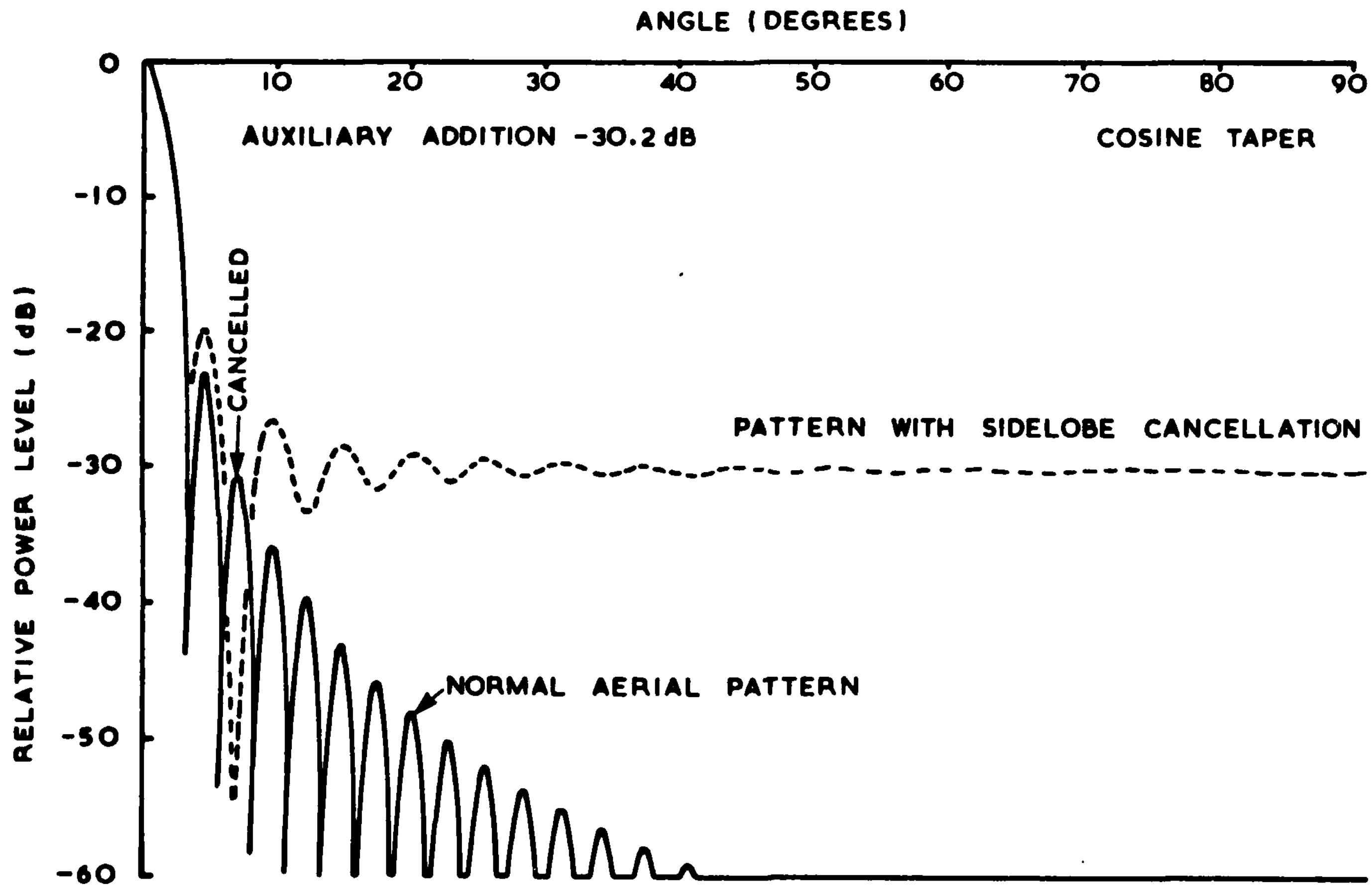

FIG. 6. EFFECT ON THE RADIATION PATTERN OF CANCELLING THE SECOND SIDELOBE

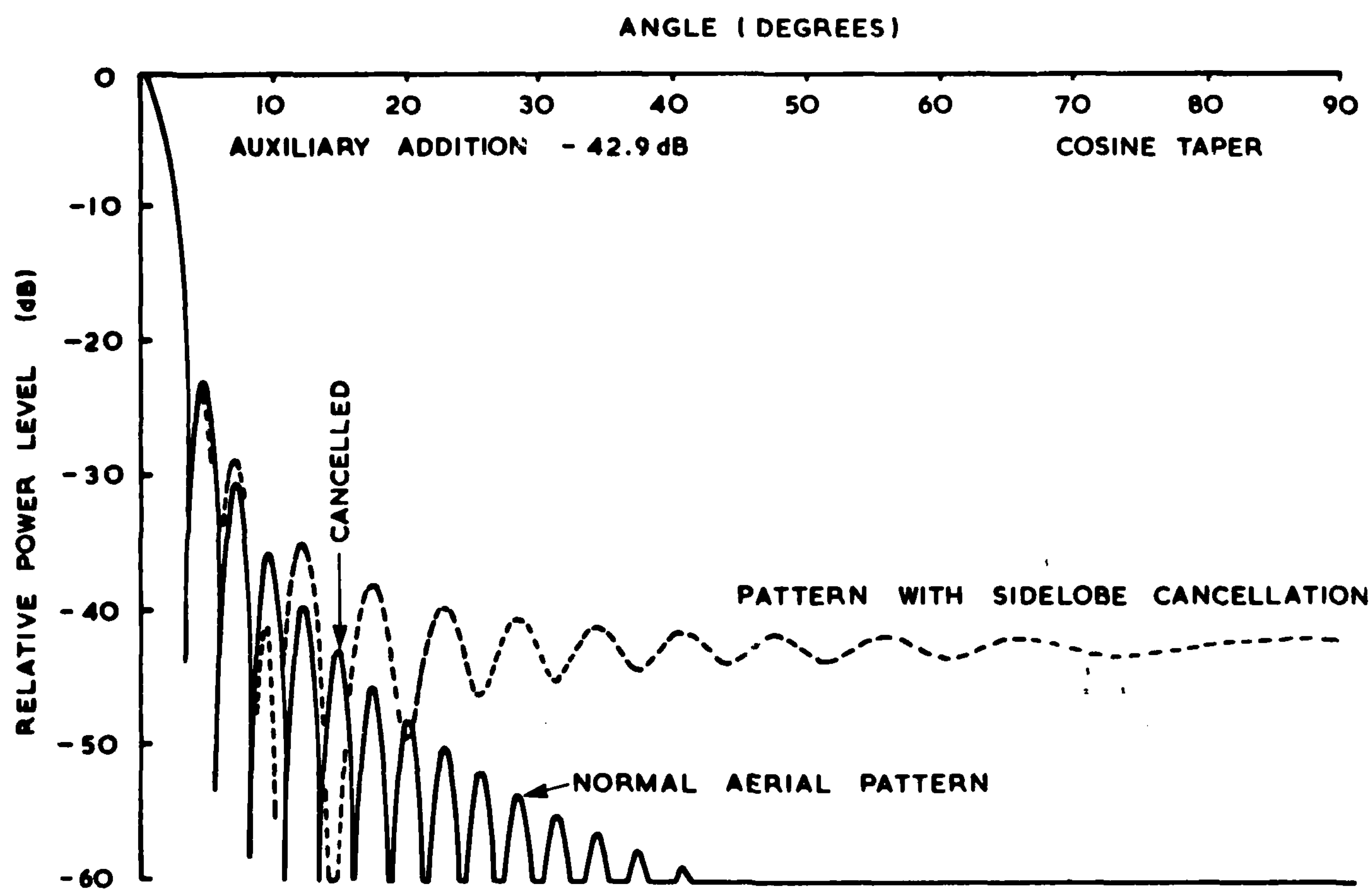

FIG. 7. EFFECT ON THE RADIATION PATTERN OF CANCELLING THE FIFTH SIDELOBE

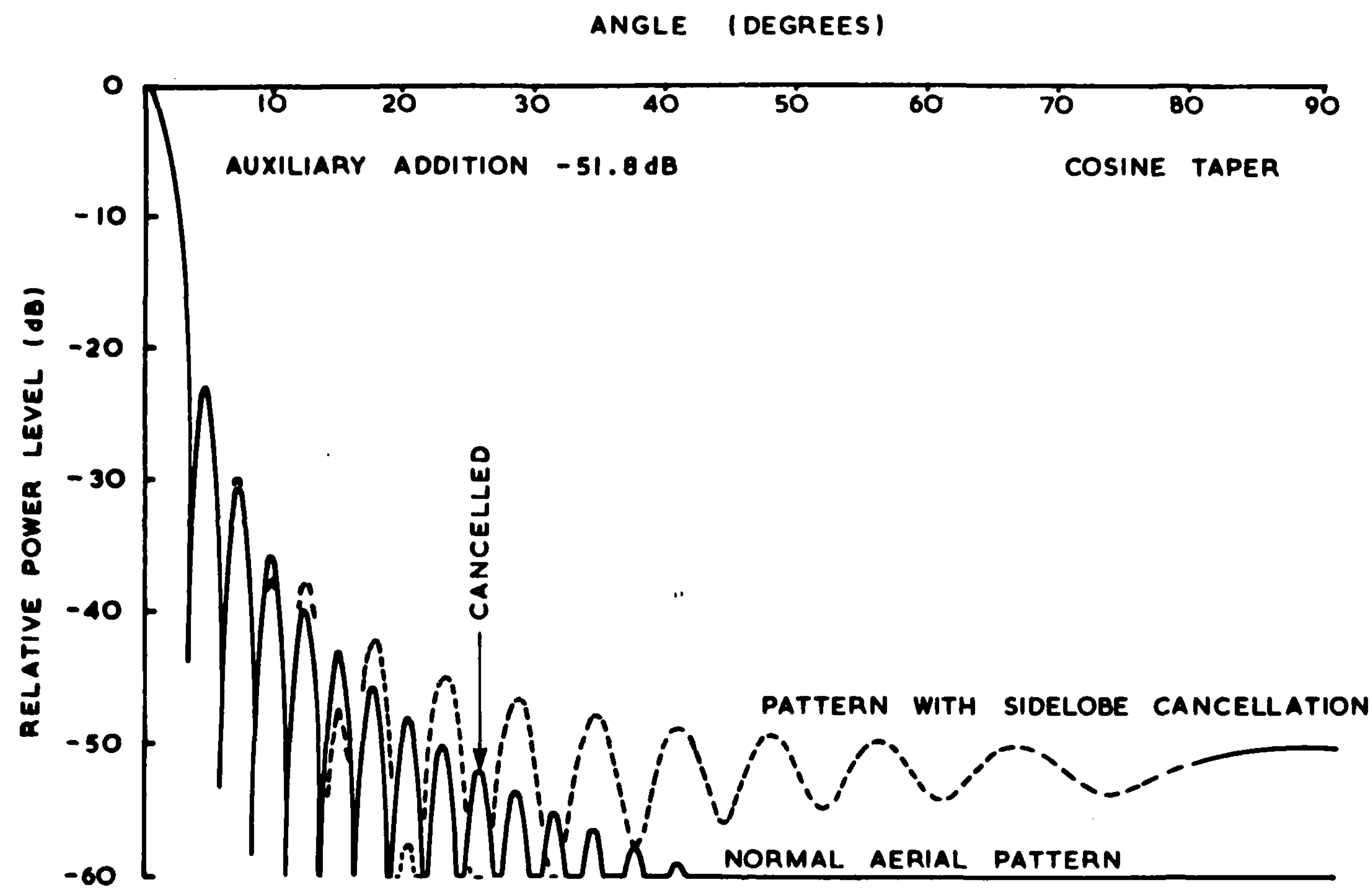

FIG. 8. EFFECT ON THE RADIATION PATTERN OF CANCELLING THE NINTH SIDELOBE

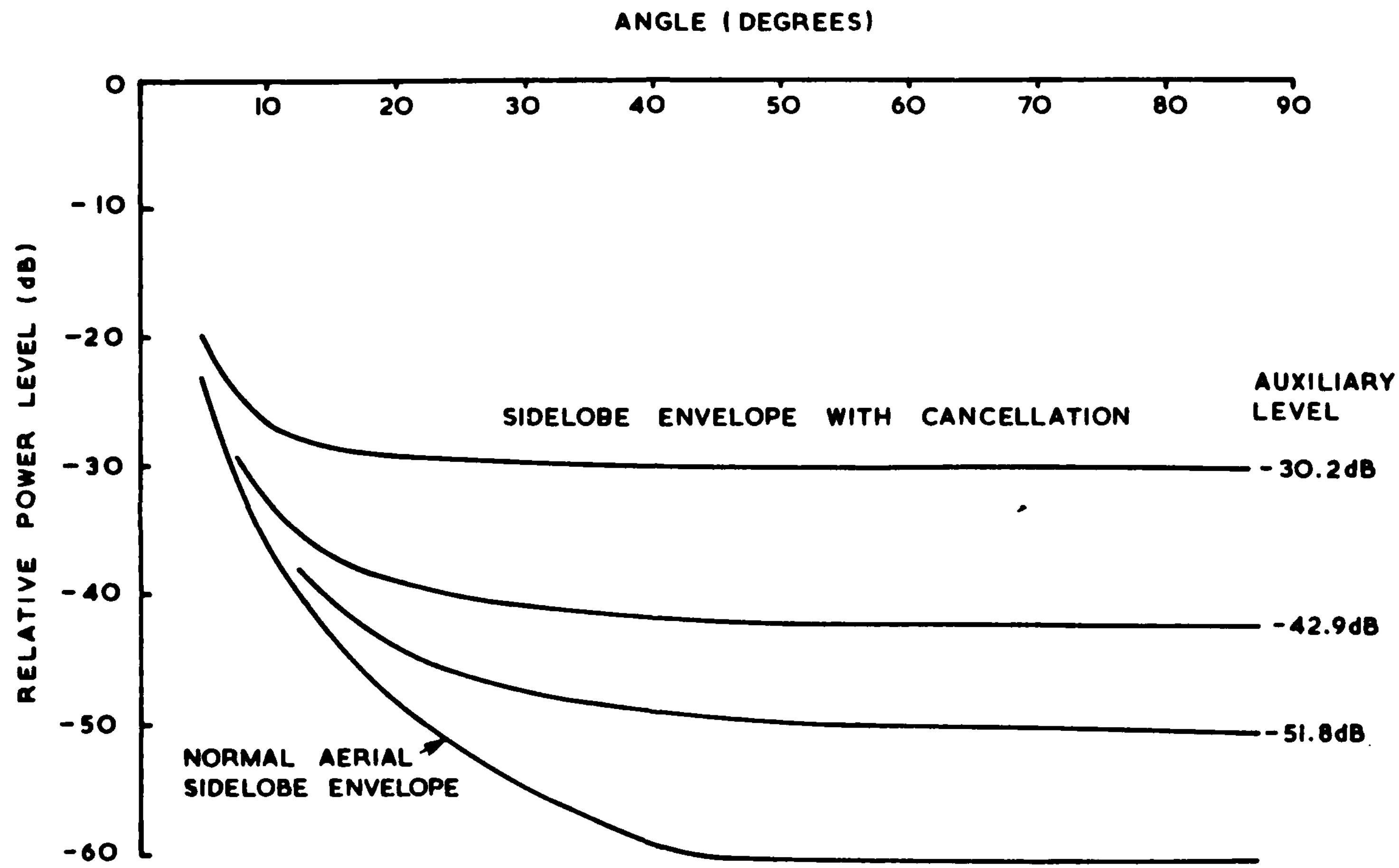

FIG. 9. PEAK SIDELOBE ENVELOPE RESULTING FROM IMPLEMENTING SIDELOBE CANCELLATION - COSINE TAPERED APERTURE DISTRIBUTION

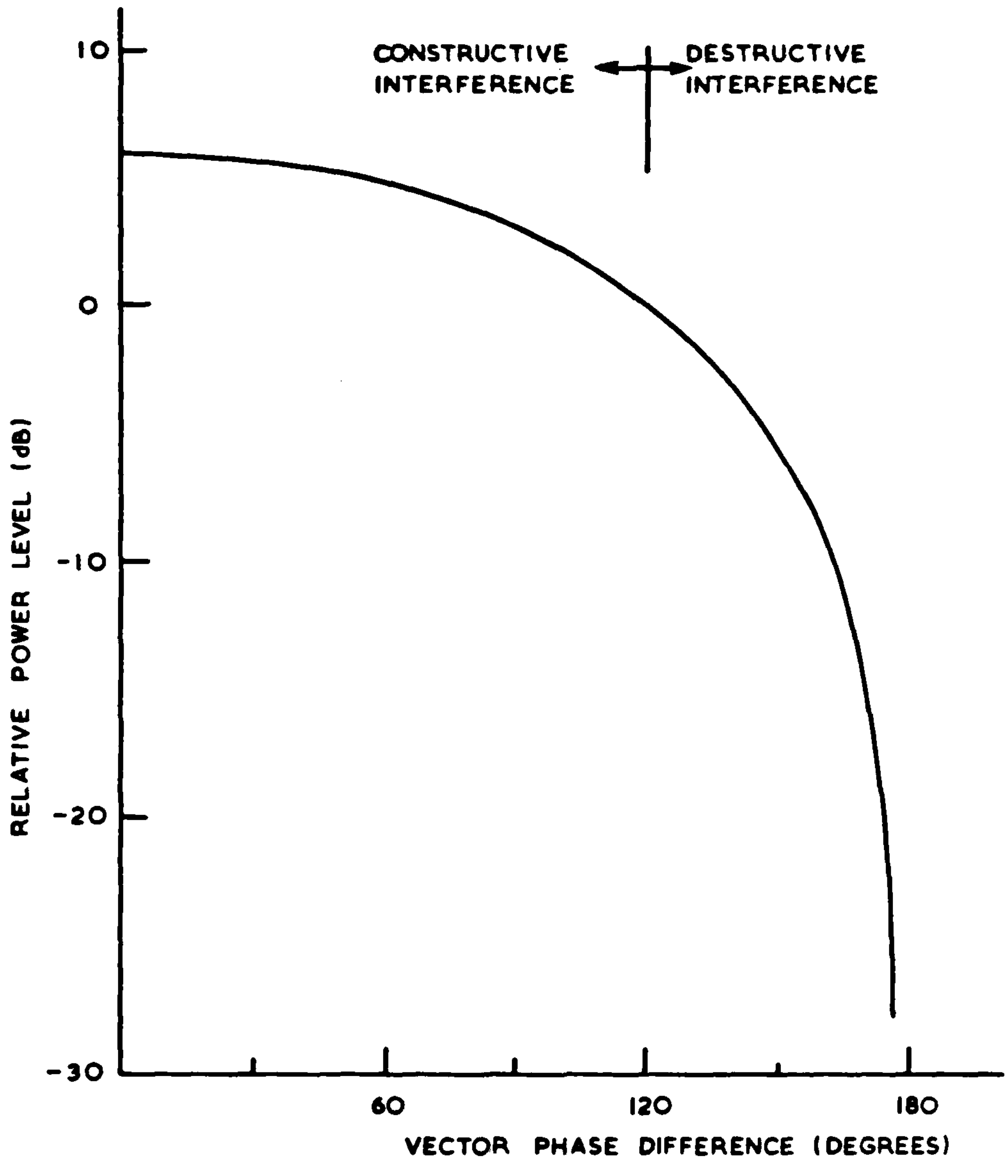

FIG. 10. RESULTANT POWER VERSUS VECTOR PHASE DIFFERENCE

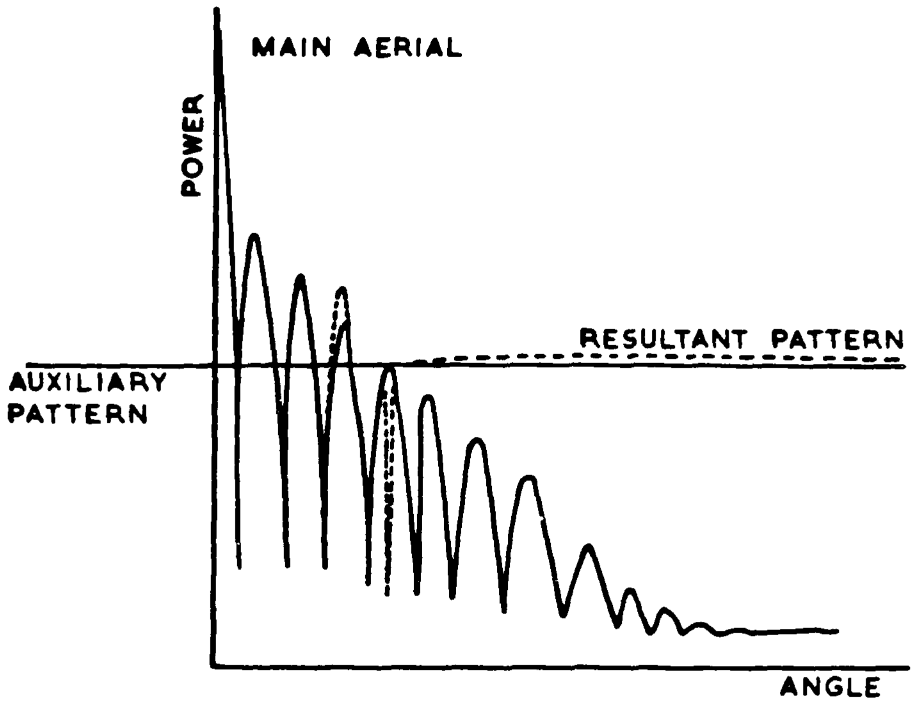

FIG.11. EFFECT OF AN OMNI AUXILIARY AERIAL

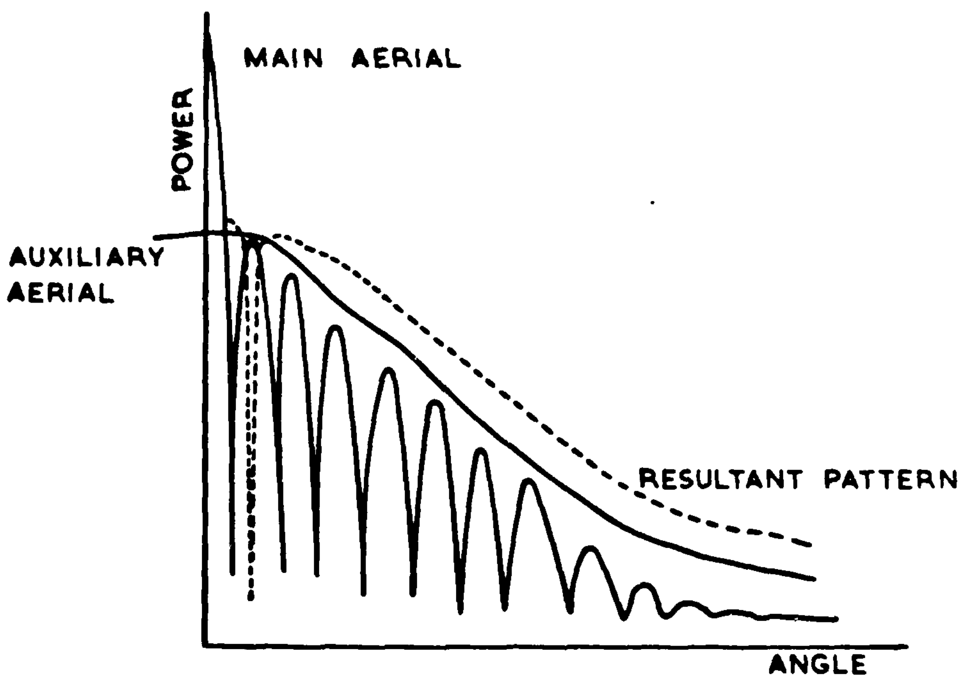

FIG.12. MATCHED SHAPED AUXILIARY AERIAL

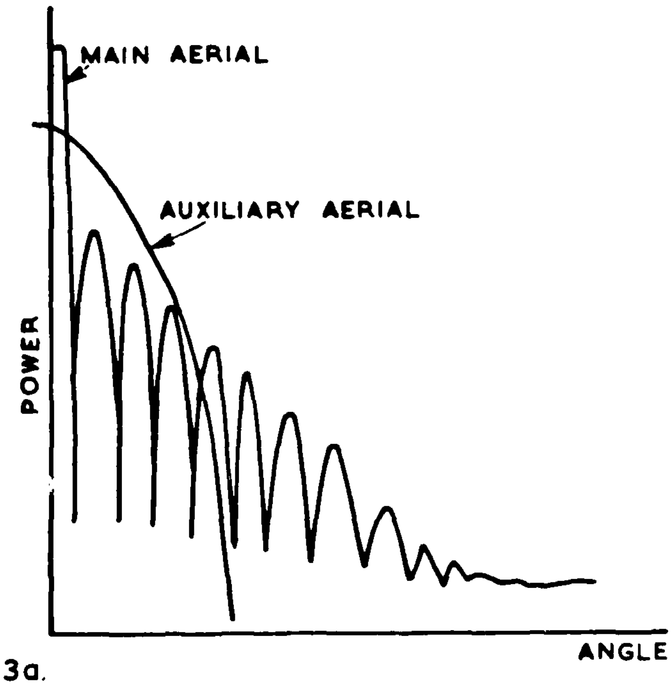

FIG. 13a.

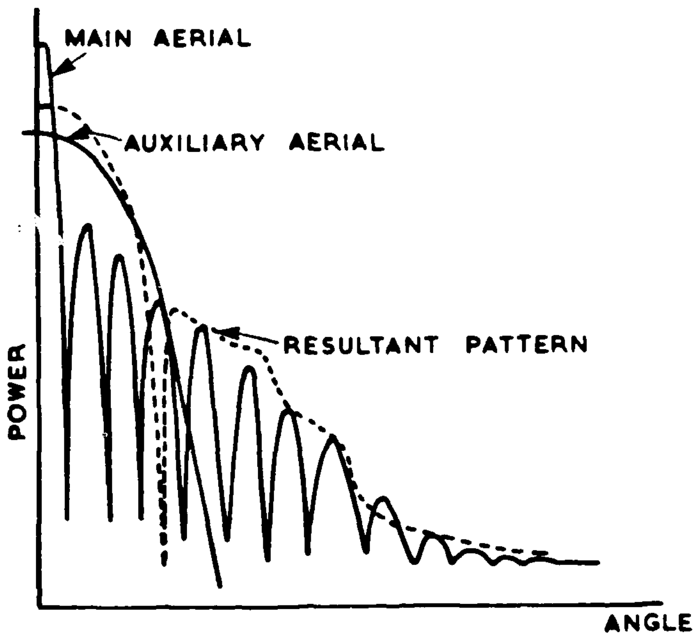

FIG. 13b.

FIG. 13. EFFECT OF A NARROW AUXILIARY AERIAL PATTERN

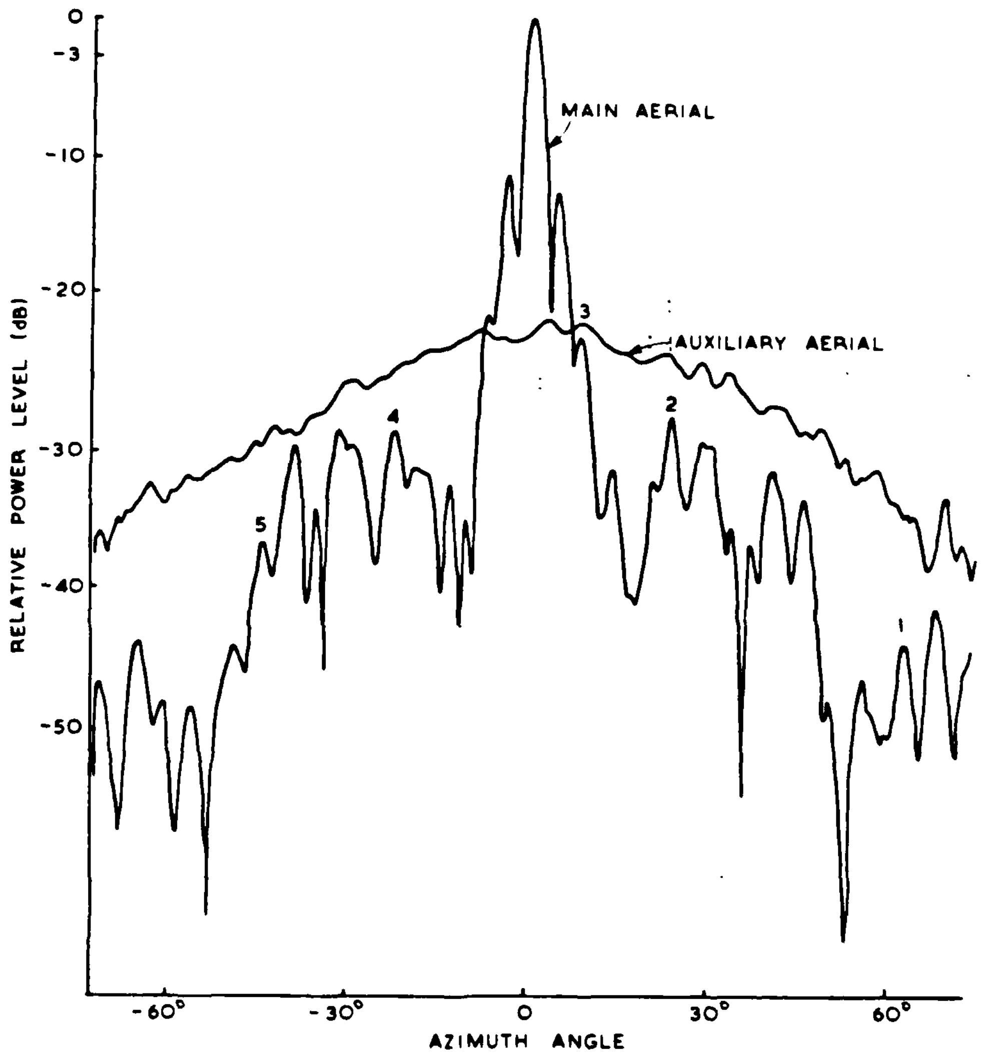

FIG 14. MAIN AND AUXILIARY PATTERNS OF S-BAND-AERIAL

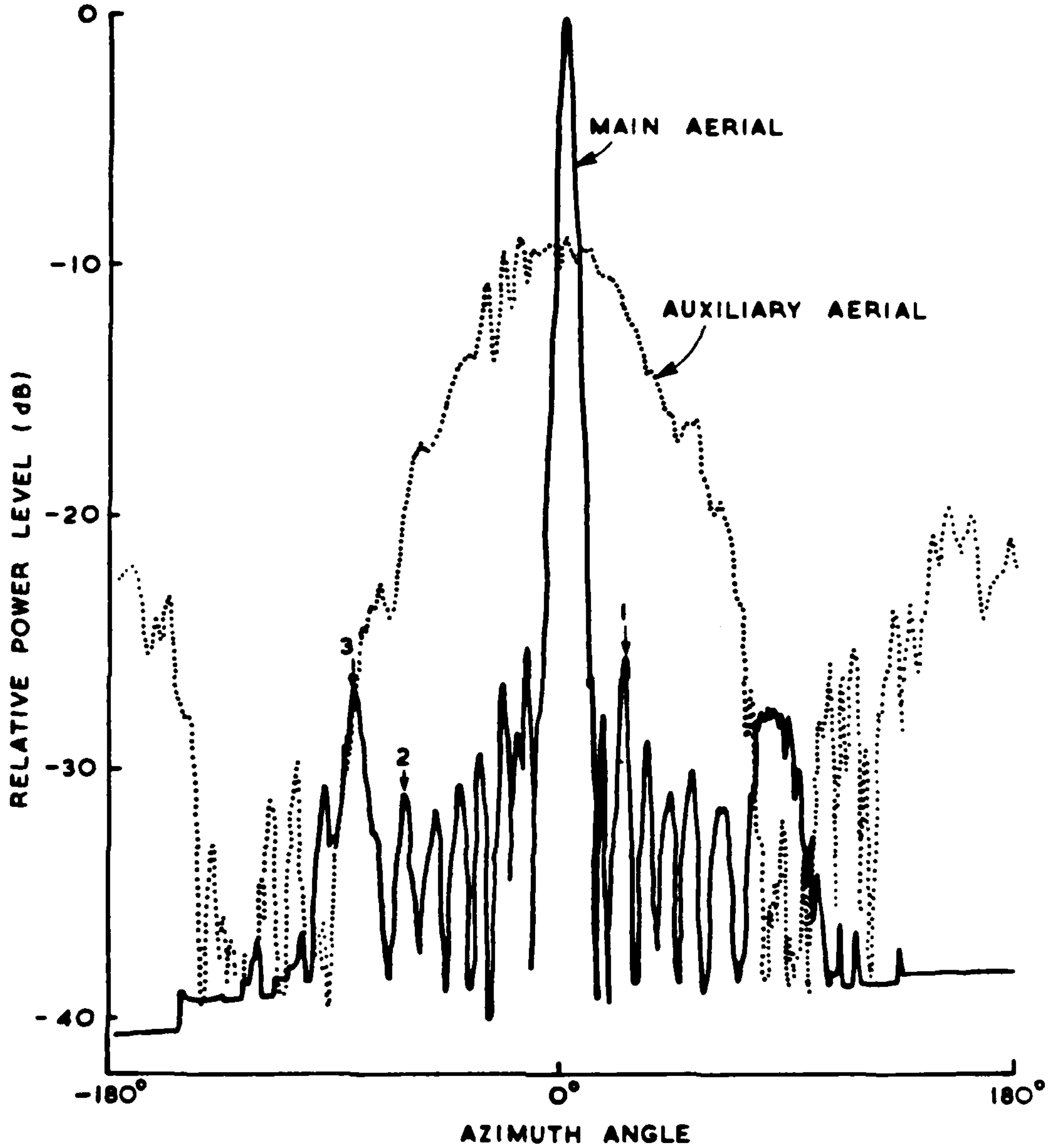

FIG. 15. MAIN AND AUXILIARY PATTERNS OF X-BAND AERIAL H-PLANE

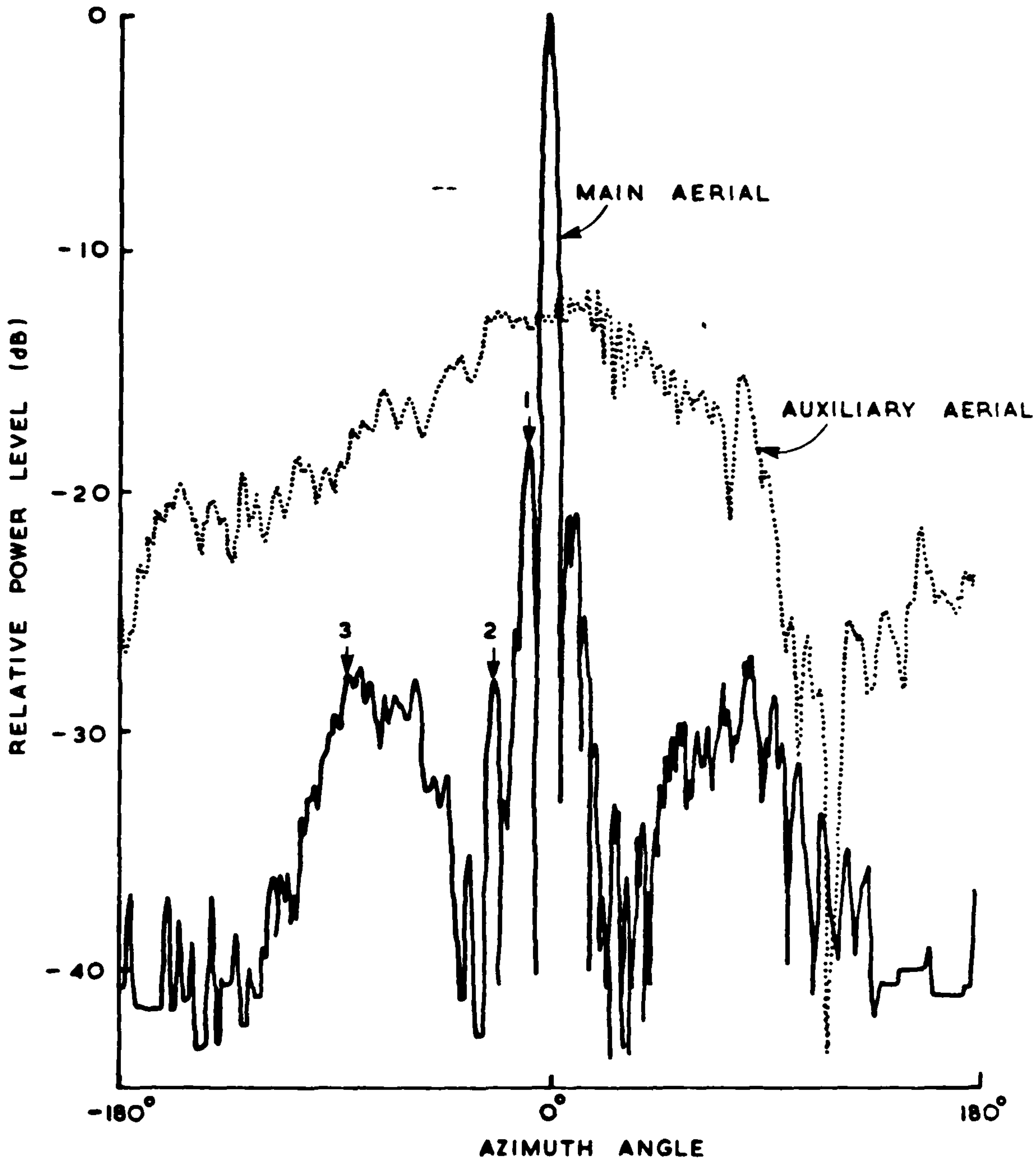

FIG.16. MAIN AND AUXILIARY PATTERNS OF X-BAND AERIAL E-PLANE

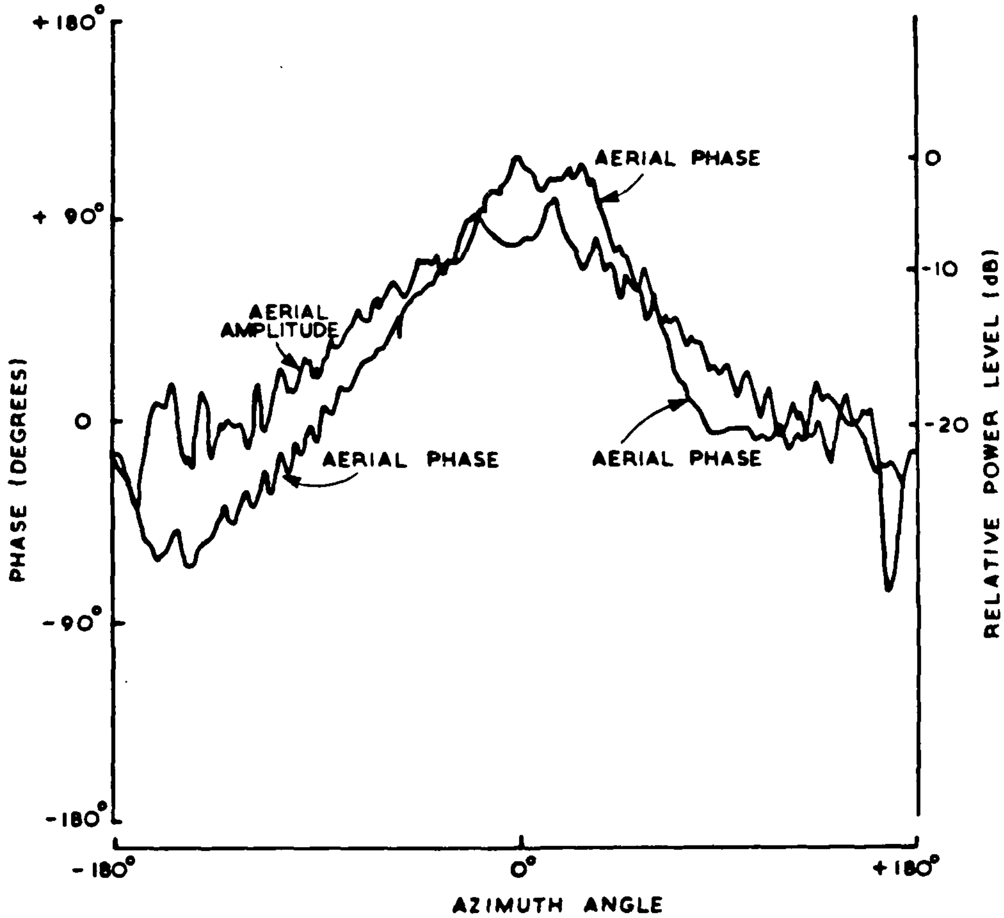

FIG 17 E-PLANE AUXILIARY AERIAL AMPLITUDE AND PHASE PLOTS

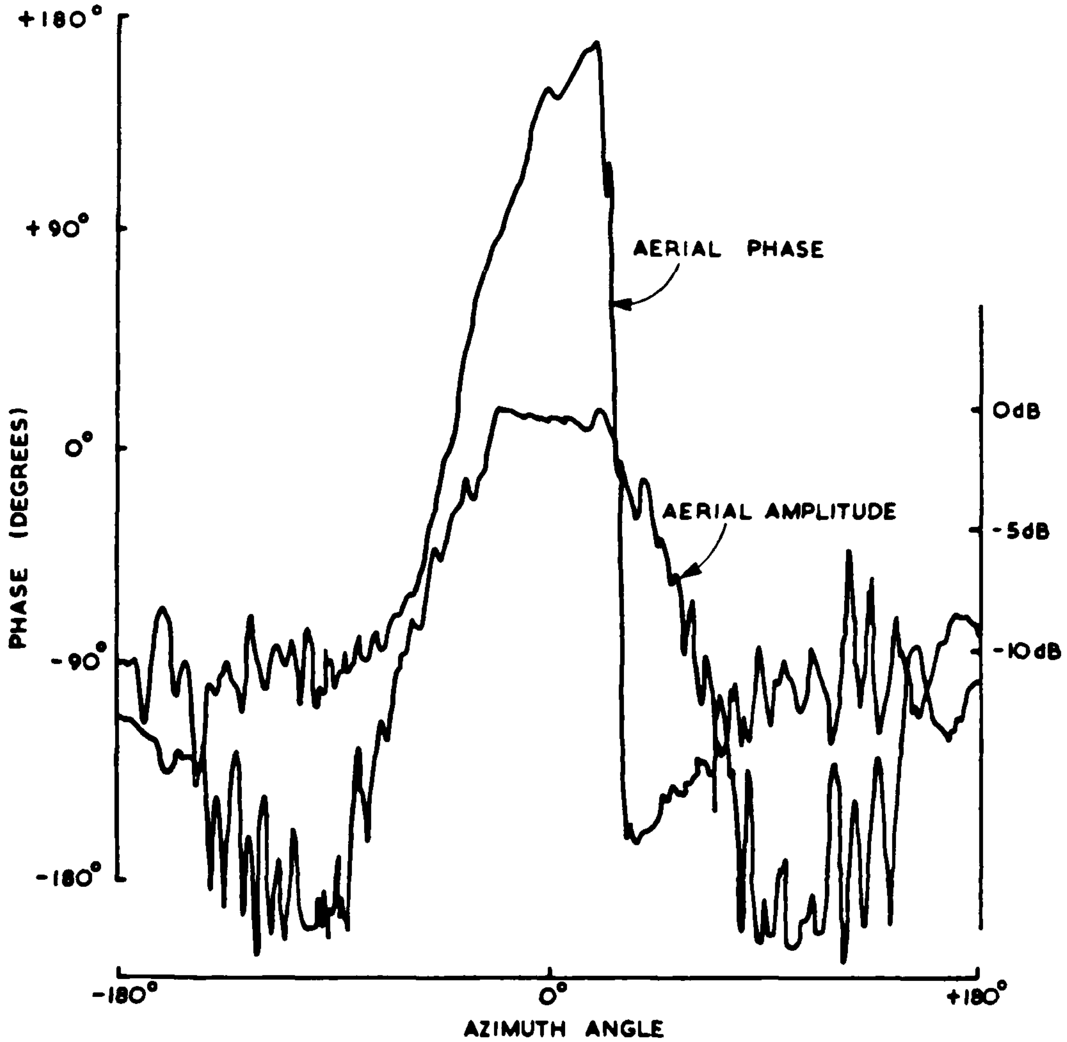

FIG. 18. H - PLANE AUXILIARY AERIAL AMPLITUDE AND PHASE PLOTS

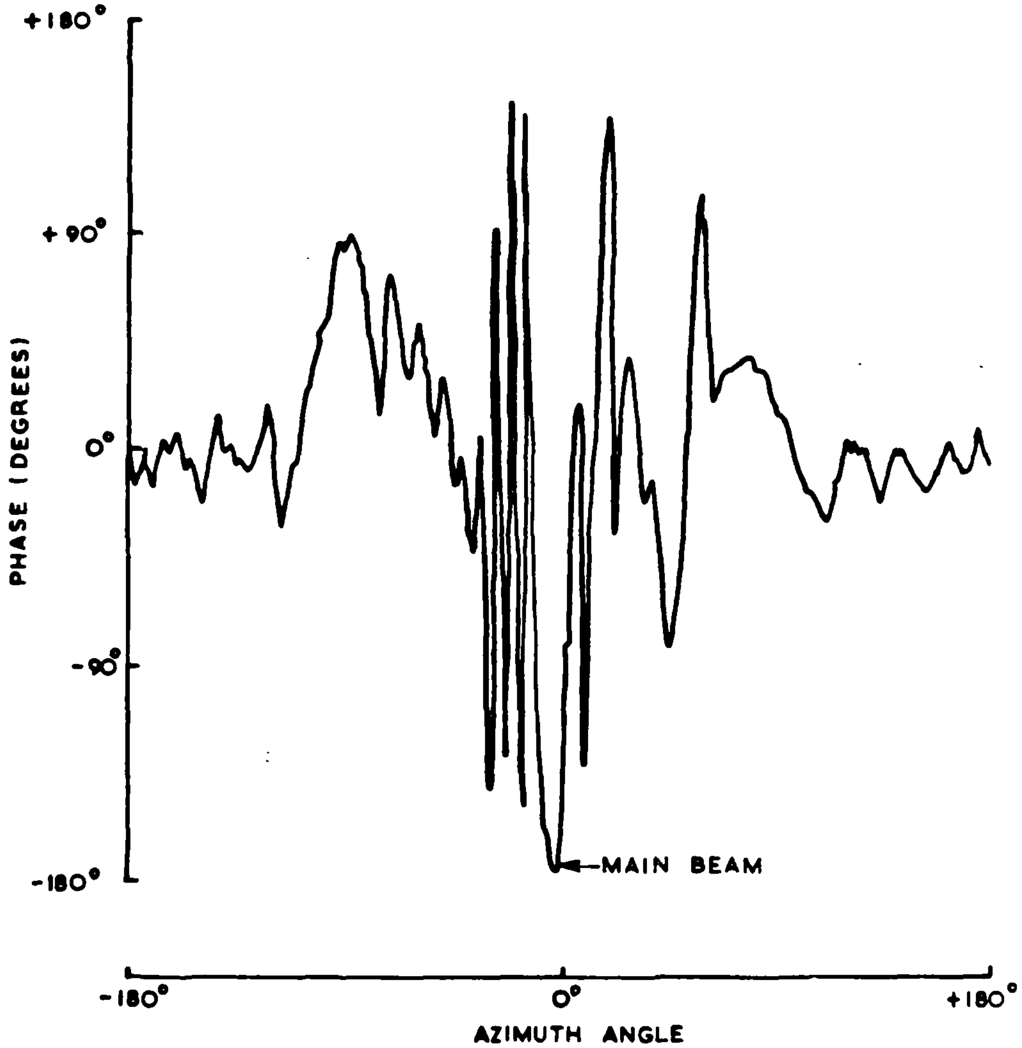

FIG. 19. MAIN AERIAL PHASE PLOT - H PLANE

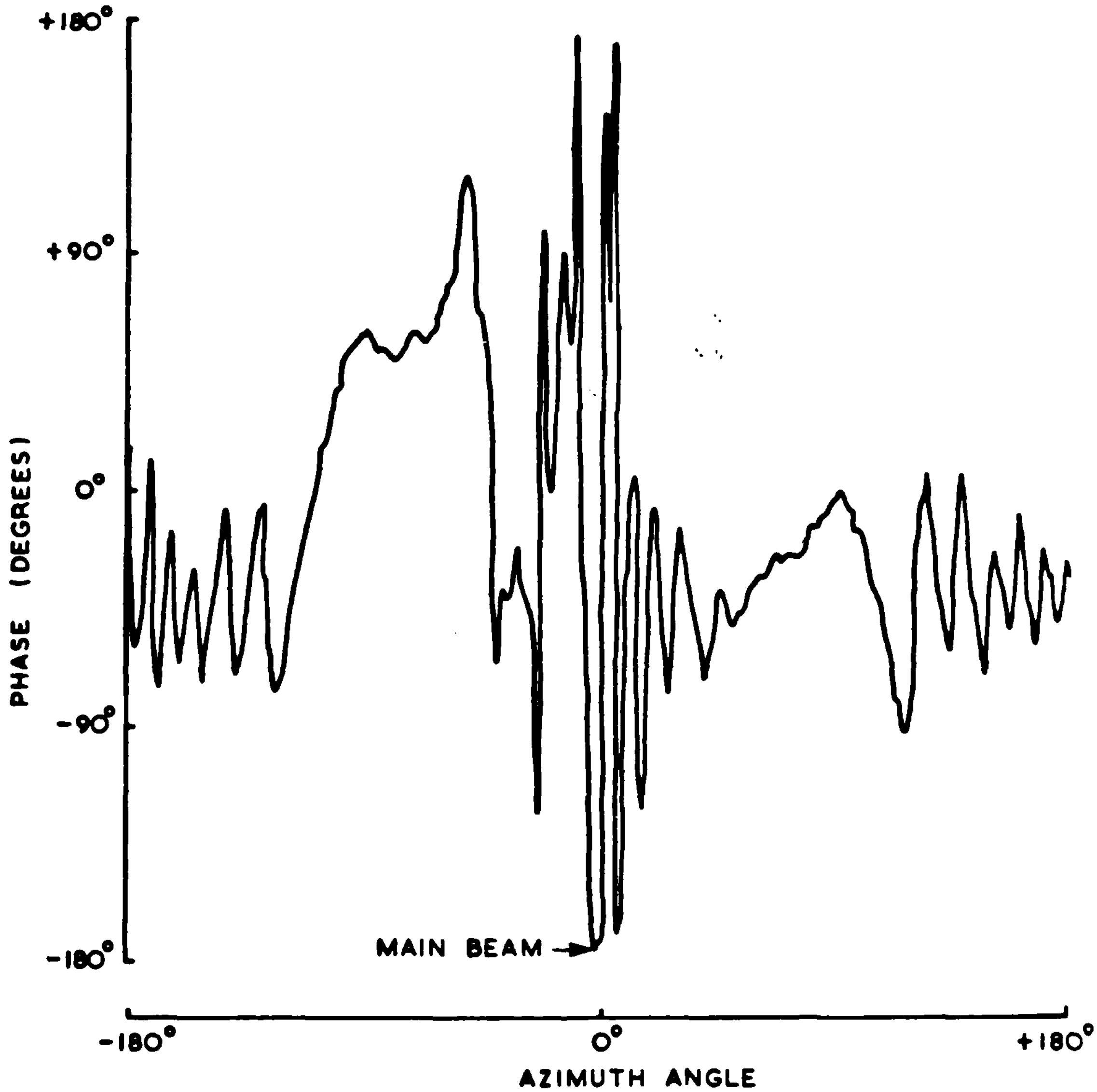

FIG. 20. MAIN AERIAL PHASE PLOT - E PLANE

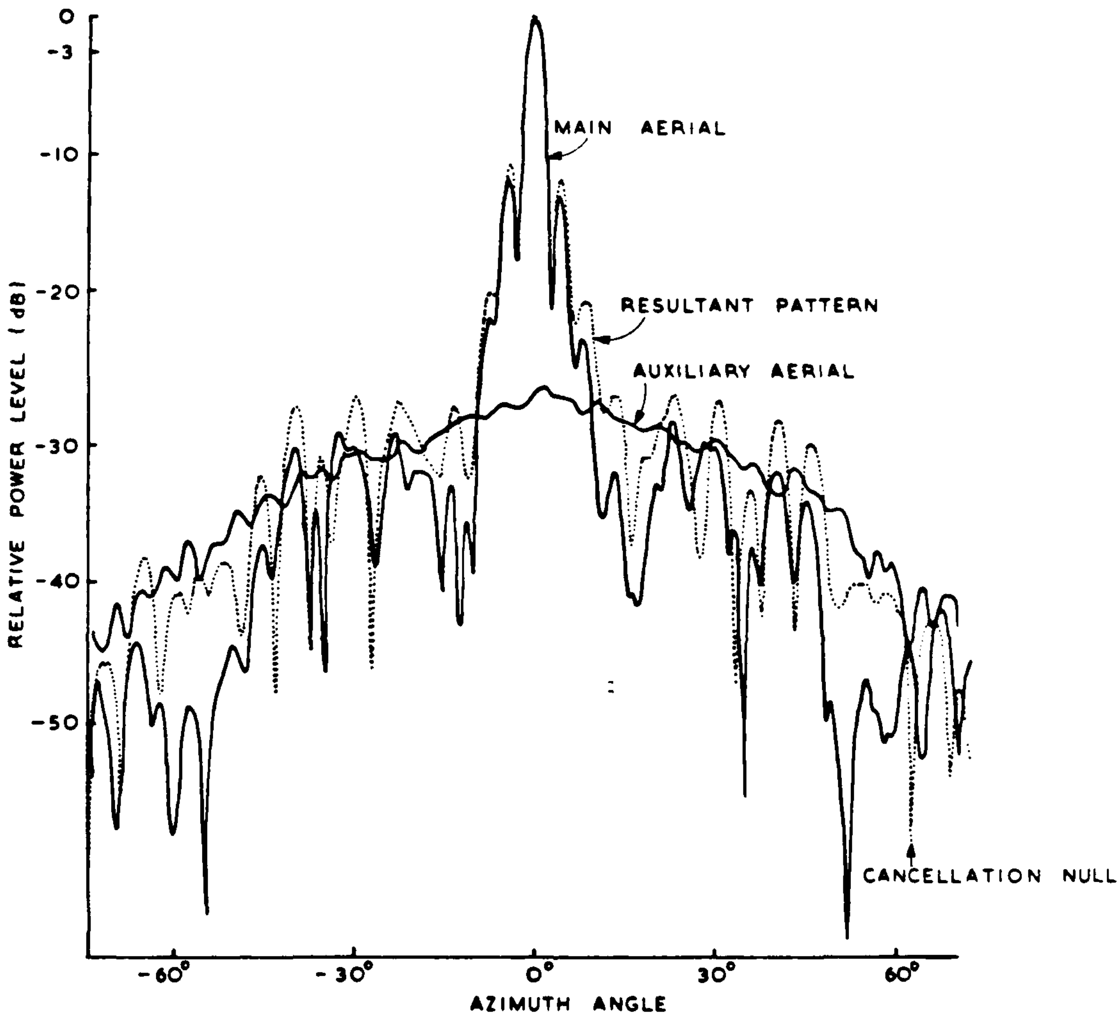

FIG 21. CANCELLATION OF SIDELOBE ONE AT +65° AZIMUTH S-BAND SYSTEM

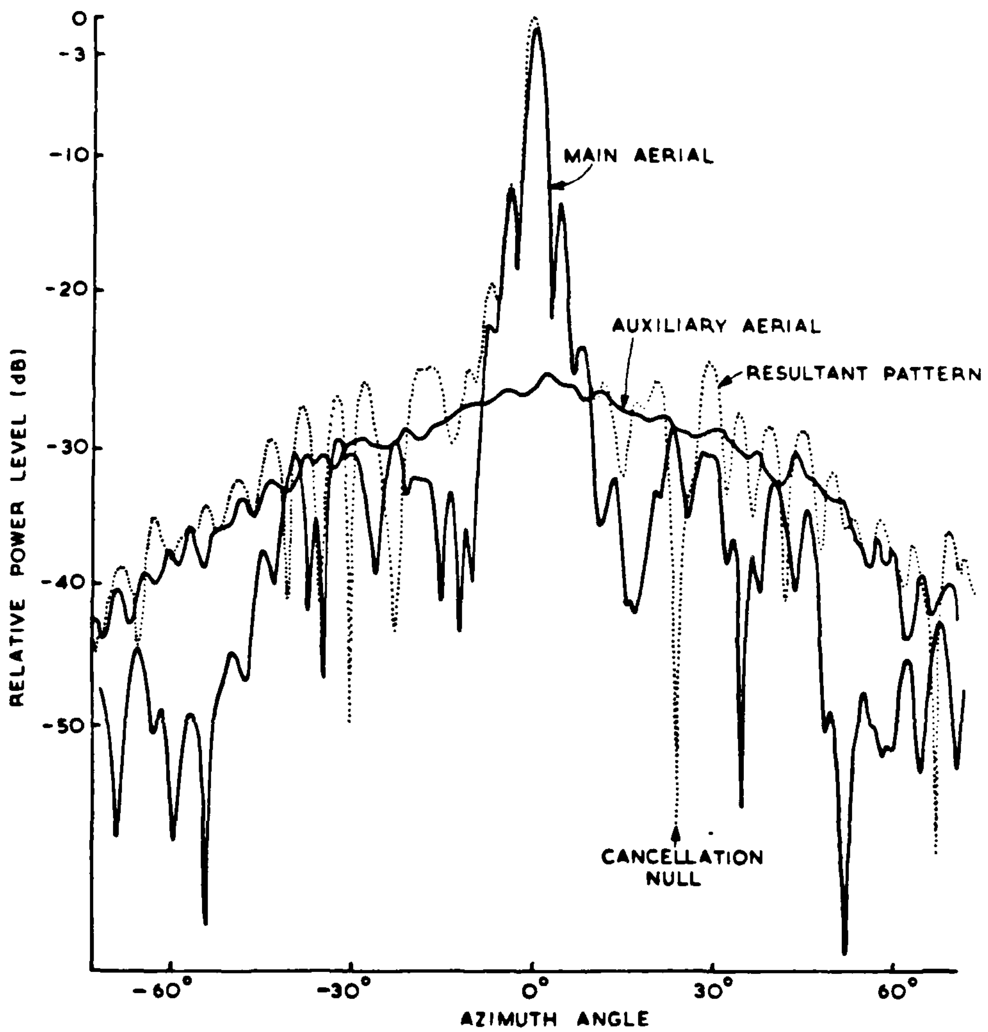

FIG 22. CANCELLATION OF SIDELOBE TWO AT + 23° AZIMUTH S-BAND SYSTEM

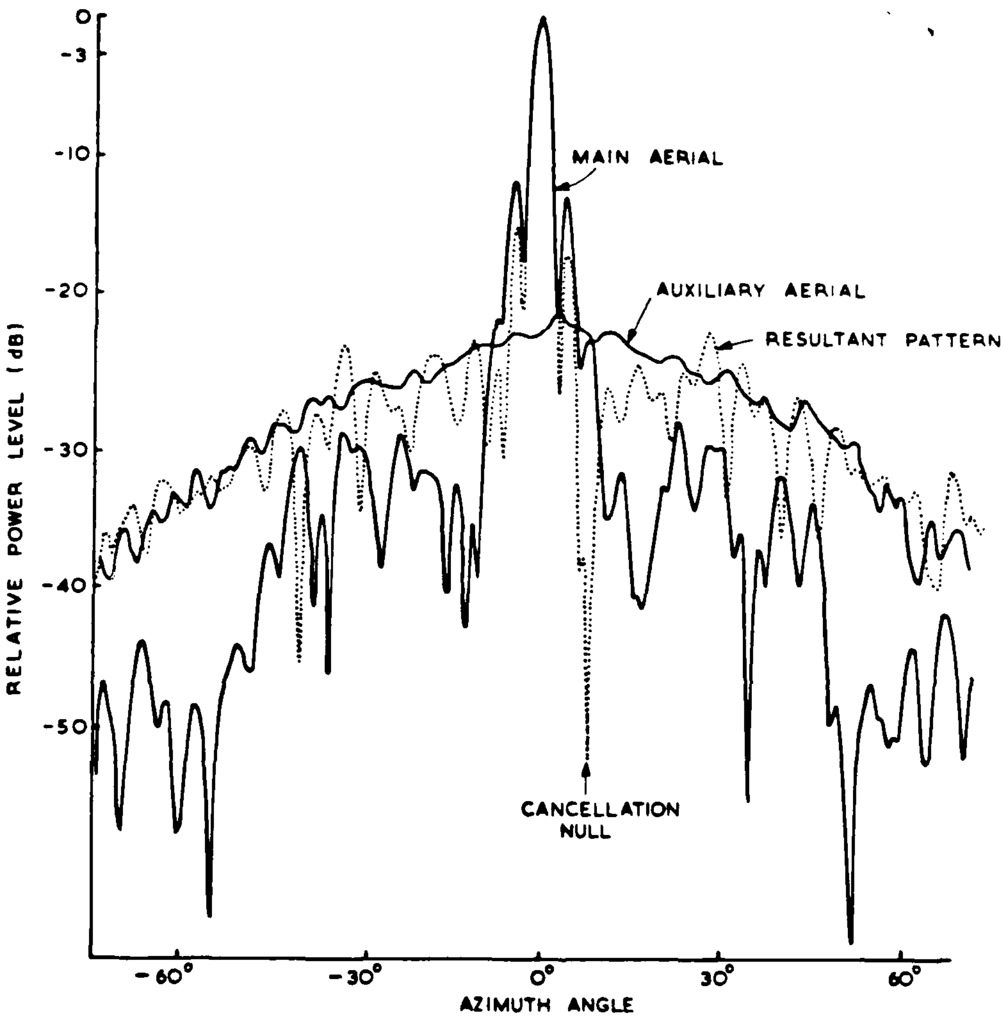

FIG. 23. CANCELLATION OF SIDELOBE THREE AT + 8° AZIMUTH S-BAND SYSTEM

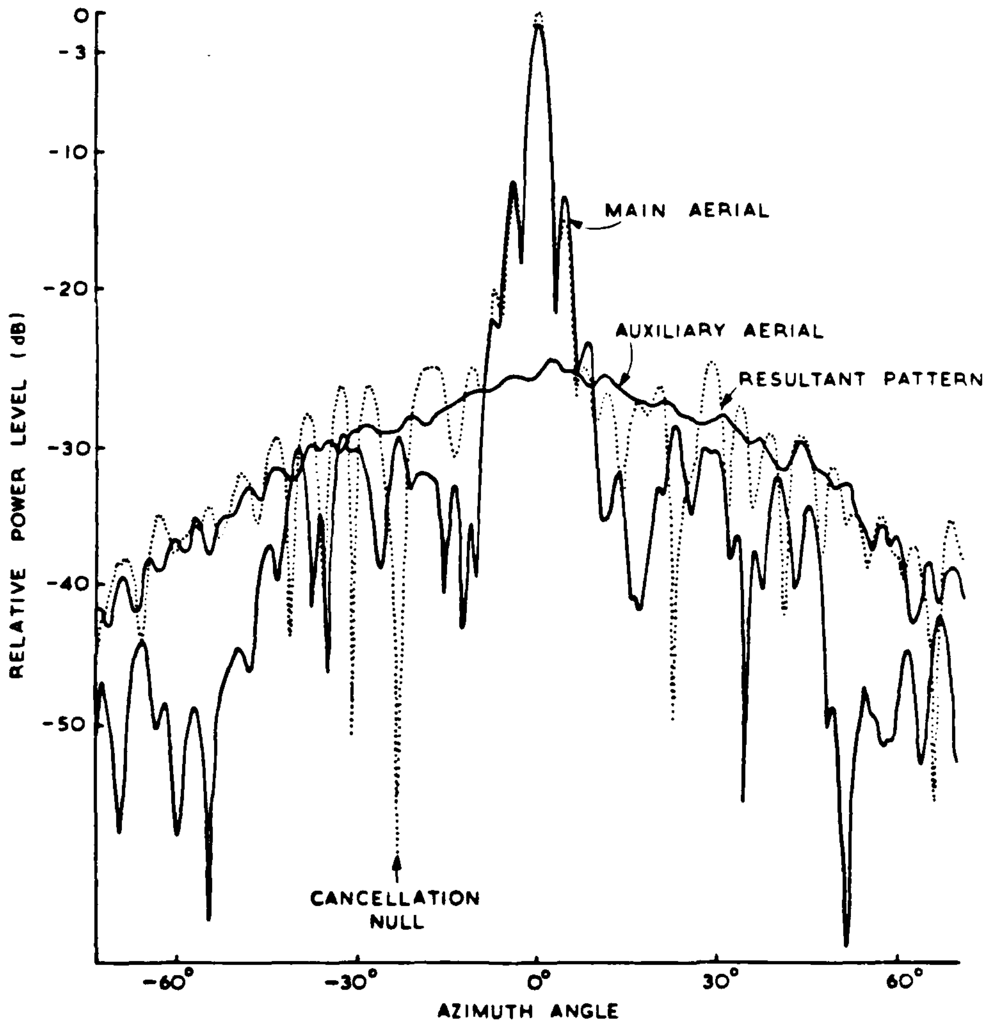

FIG 24. CANCELLATION OF SIDELOBE FOUR AT -25° AZIMUTH S-BAND SYSTEM

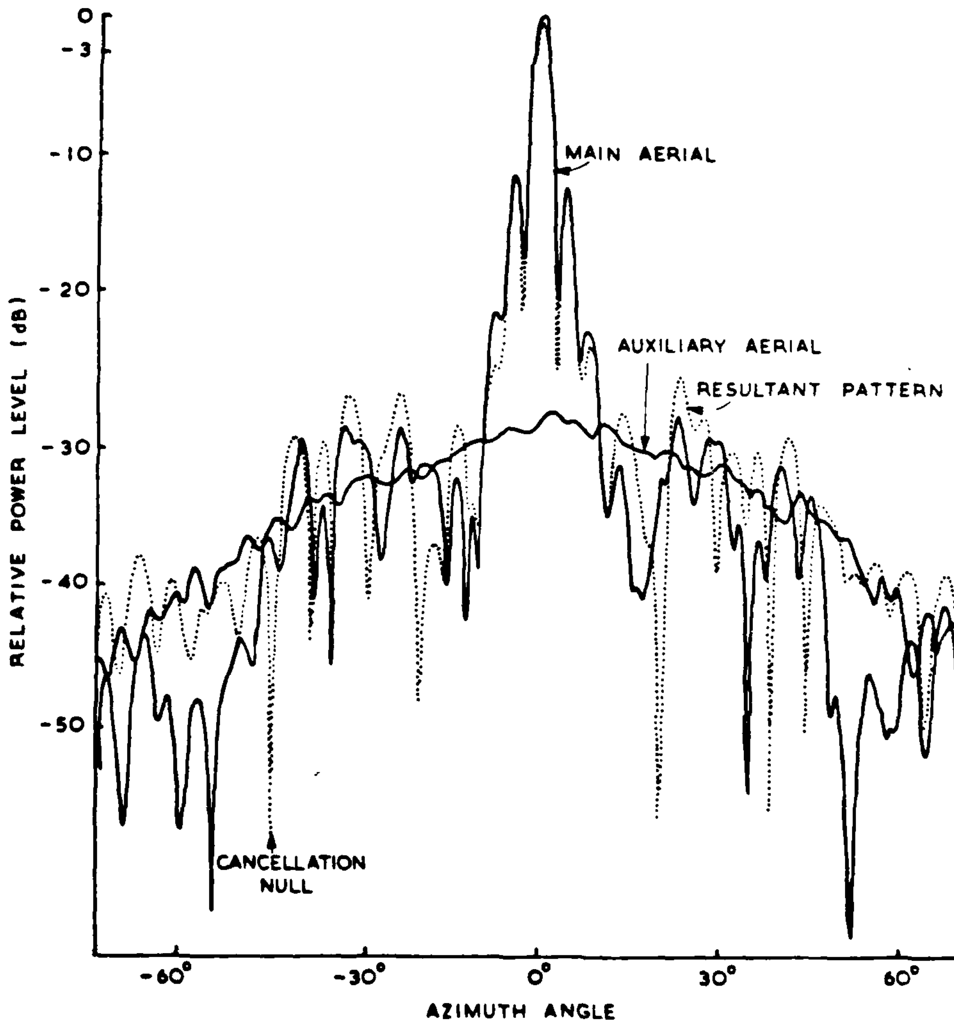

FIG 25. CANCELLATION OF SIDELOBE FIVE AT -48° AZIMUTH S-BAND SYSTEM

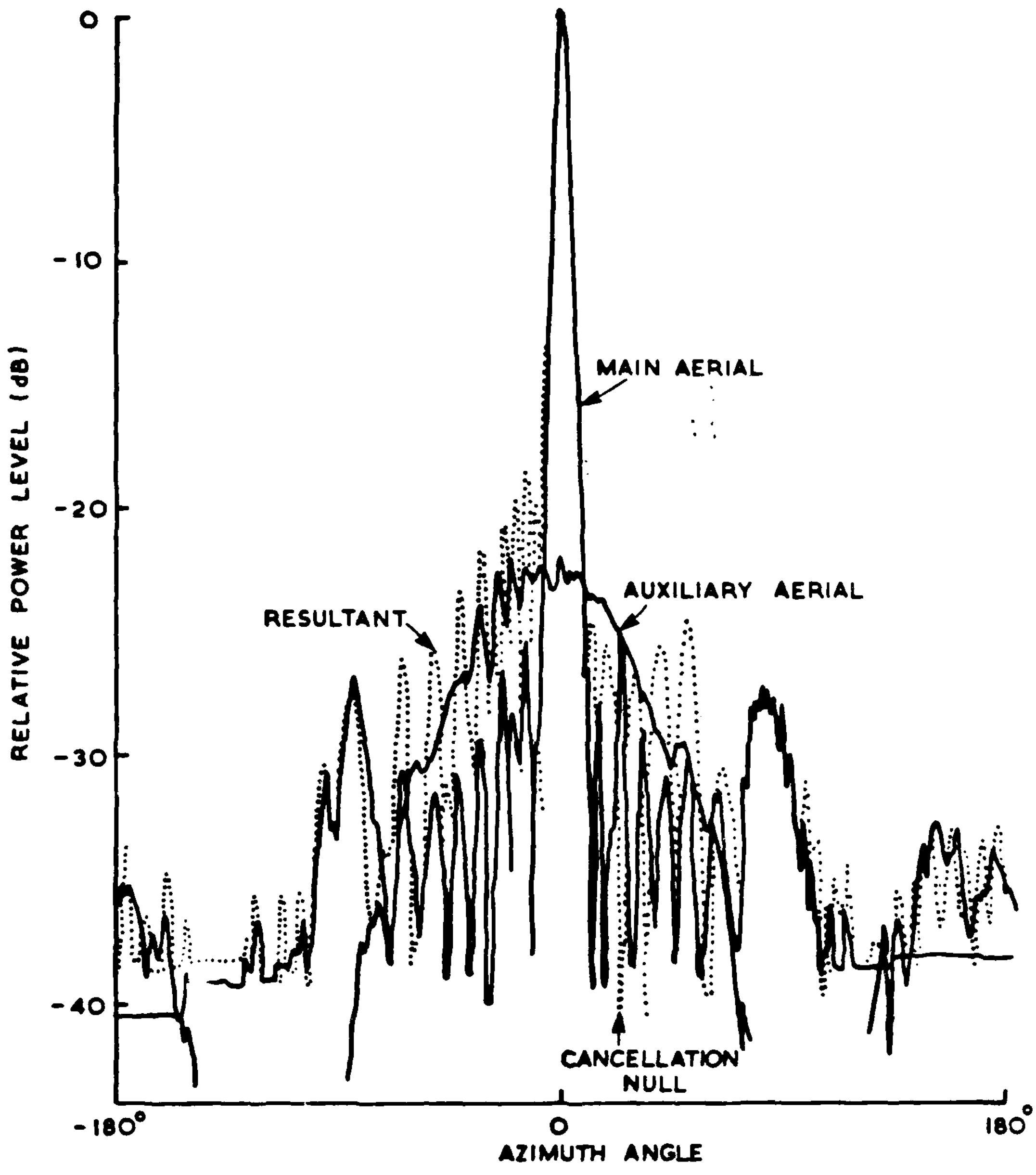

FIG. 26. CANCELLATION OF SIDELOBE ONE AT +24° AZIMUTH X - BAND SYSTEM H - PLANE

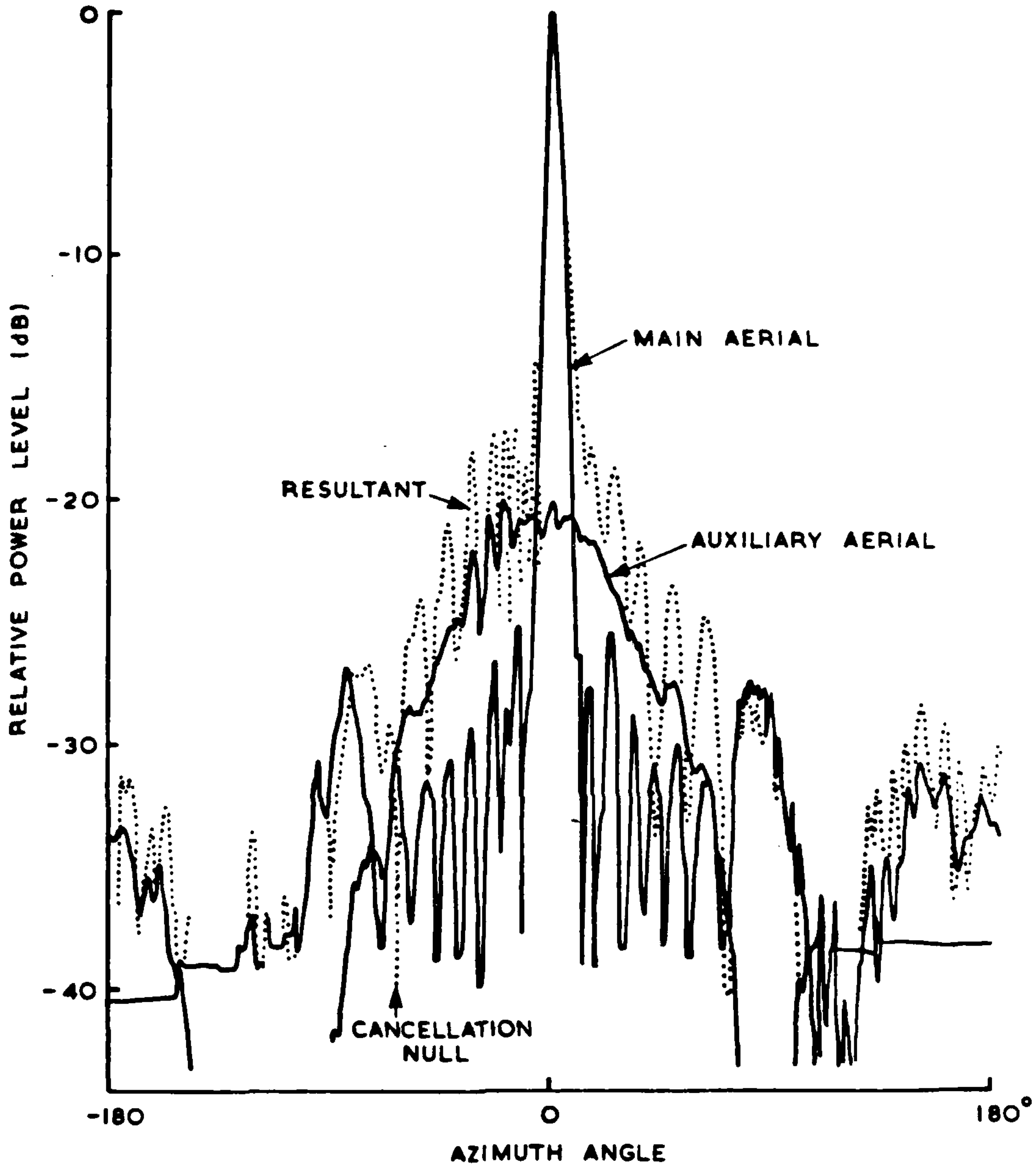

FIG. 27. CANCELLATION OF SIDELOBE TWO AT - 63° AZIMUTH X - BAND SYSTEM H - PLANE

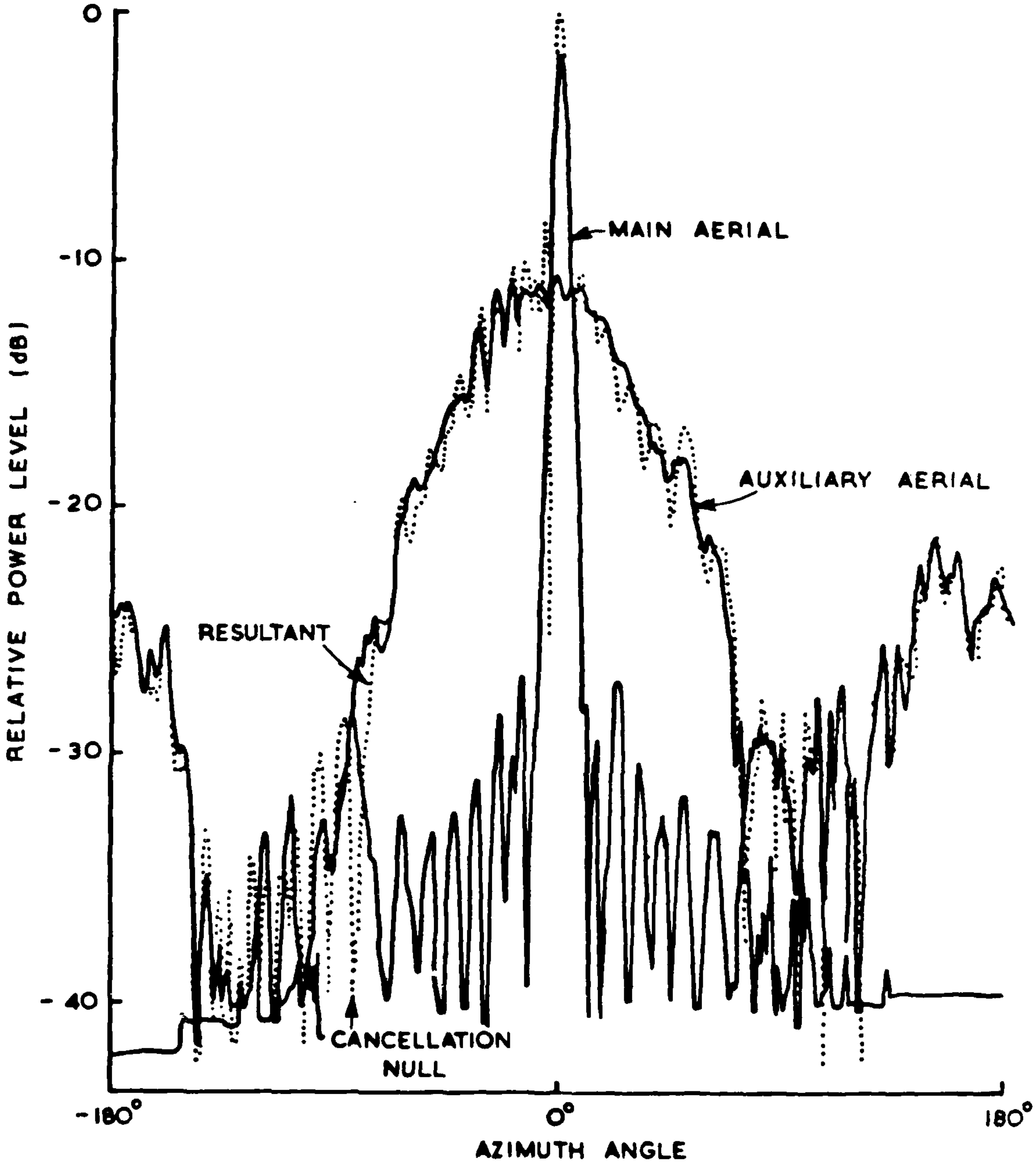

FIG. 28. CANCELLATION OF SIDELOBE THREE AT-83° AZIMUTH X - BAND SYSTEM H - PLANE

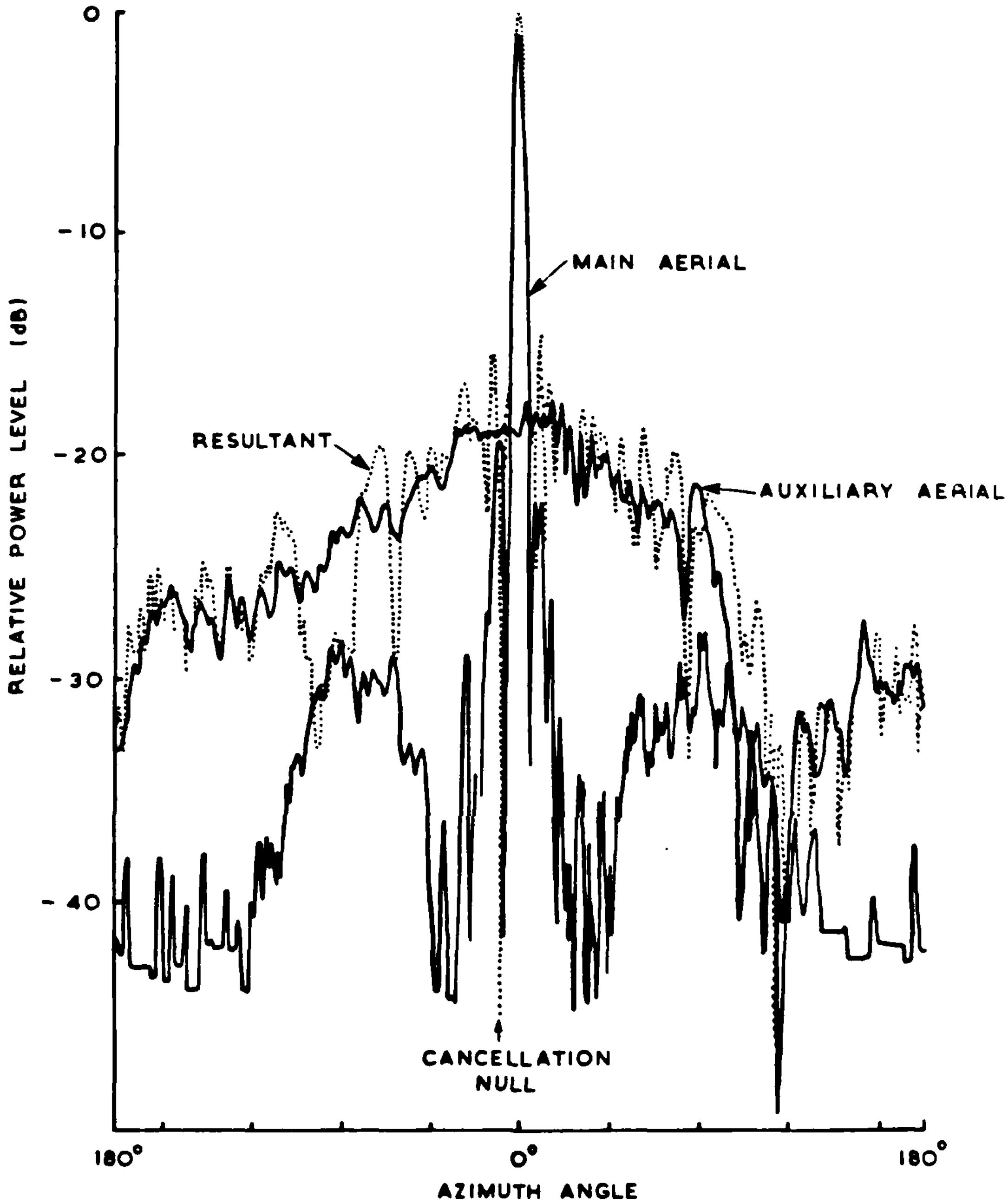

FIG. 29 CANCELLATION OF SIDELOBE ONE AT -8° AZIMUTH X-BAND SYSTEM E-PLANE

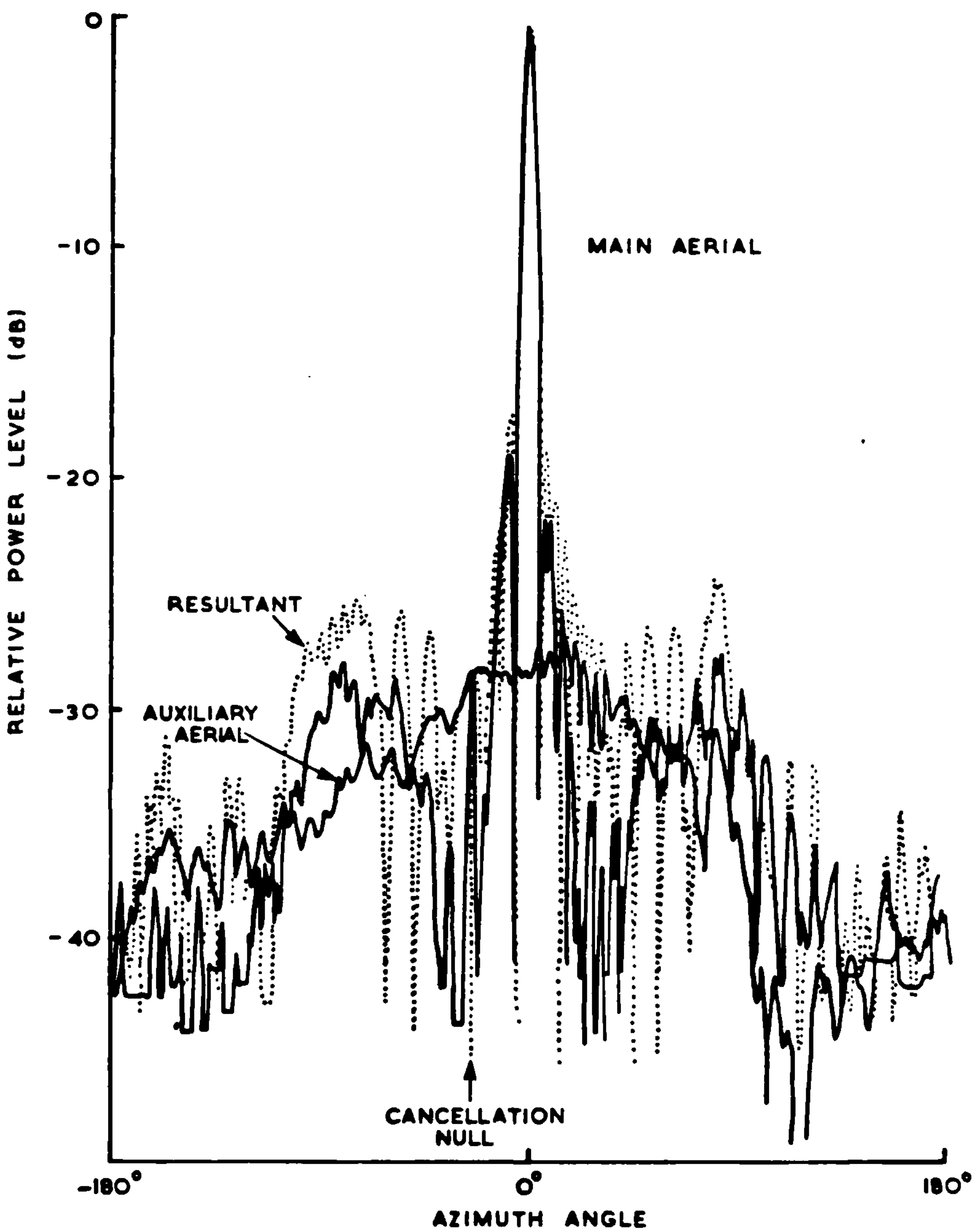

FIG. 30. CANCELLATION OF SIDELOBE TWO AT -24° AZIMUTH X-BAND SYSTEM E-PLANE

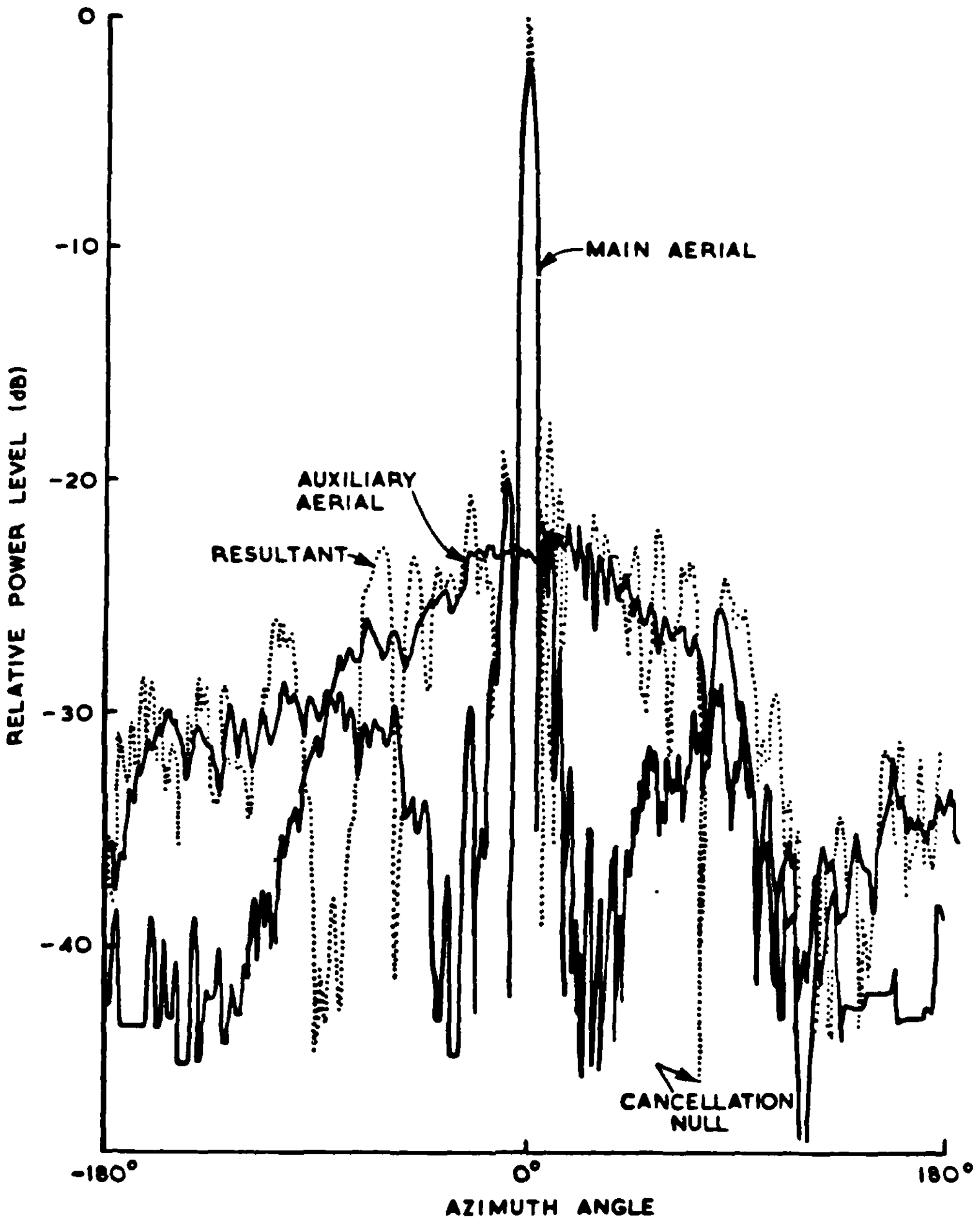

FIG. 31. CANCELLATION OF SIDELOBE THREE AT + 78° AZIMUTH X-BAND SYSTEM E-PLANE

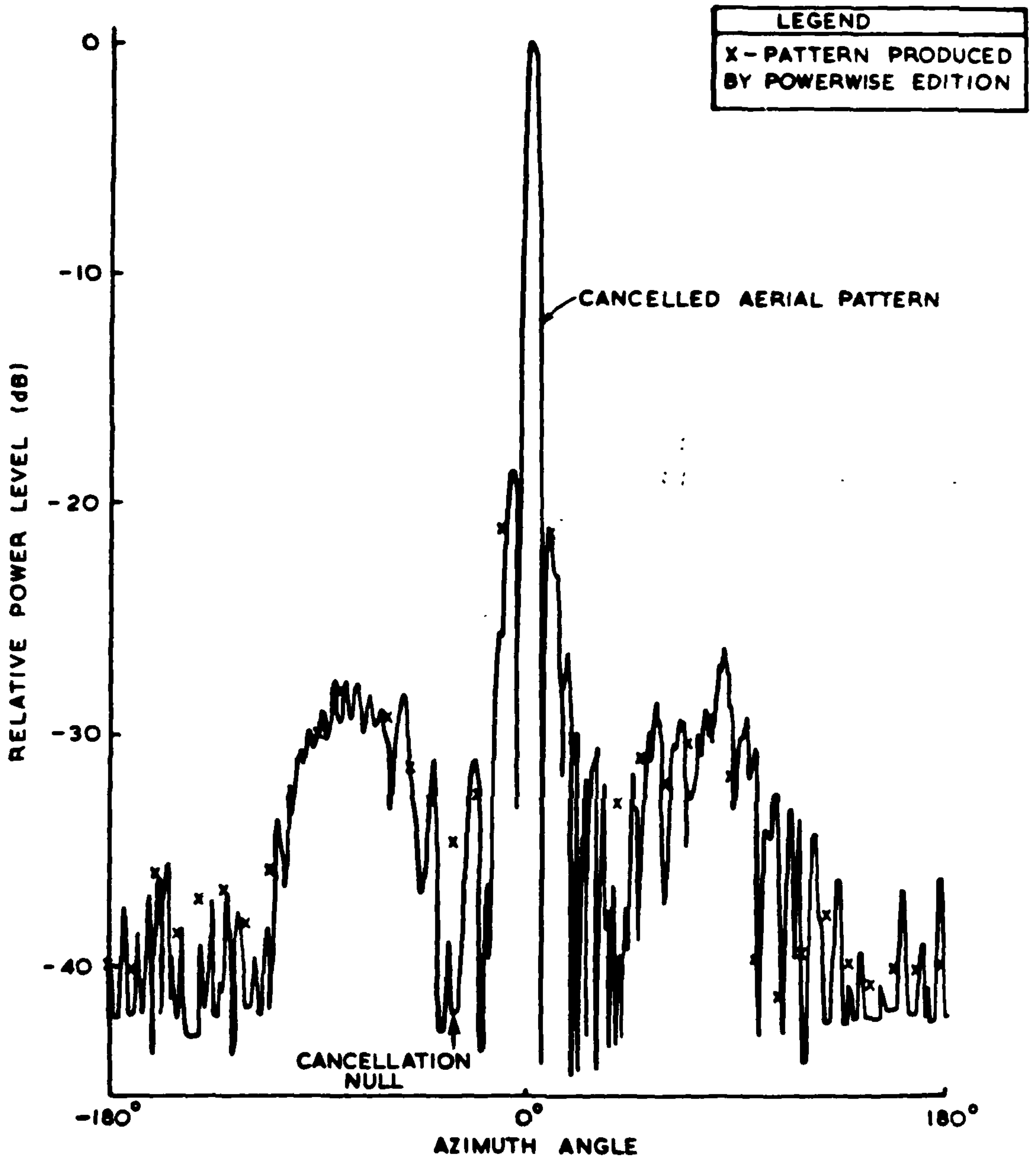

FIG. 32. COMPARISON OF CANCELLED PATTERN AND RESULT OF ADDITION OF POWERS FROM MAIN AND AUXILIARY AERIAL PATTERNS

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